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UNITED STATES
DEPARTMENT OF AGRICULTURE
CIRCULAR No. 380

Washington, D. C. March 1936

EROSION CONTROL ON MOUNTAIN ROADS

By

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Forest Service

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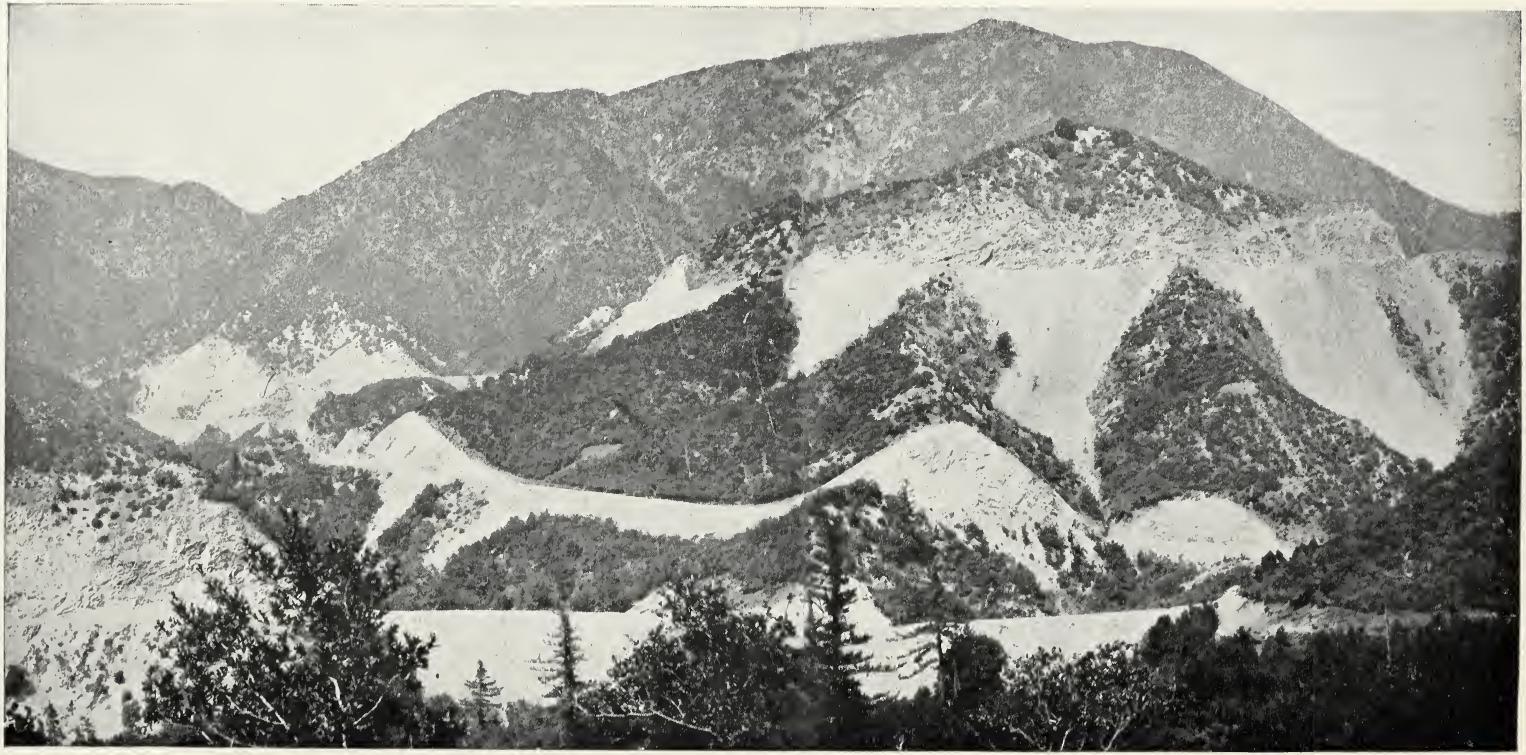

High-standard roads in steep mountains cause startling disfigurement of the landscape and serious damage from erosion of the unstable fill slopes. This view shows portions of three legs of a double switchback on the Angeles Crest Highway in the Arroyo Seco, Angeles National Forest, Calif.

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INTRODUCTION

The rapid increase of motor traffic into the mountainous parts of the country during recent years has compelled the building of many new high-standard roads and the reconstruction of old roads along modern lines. Much of this traffic is pleasure bent, and the new roads are devoted largely to the opening of recreational areas, particularly in the national forests and national parks. That these roads often disfigure the very charms they are intended to reveal is one of the unfortunate results of the high standards on which they are built and the rugged topography which they necessarily traverse. Another result, even more serious from the economic viewpoint, is the long train of damages from erosion beyond the rights of way for which the new roads are almost invariably, though by no means unavoidably, responsible (pls. 1 and 2, *A*).

The purpose of this circular is threefold: (1) To call attention to the seriousness of the problem; (2) to indicate preventive measures which can be incorporated in the planning and building of roads; and (3) to describe corrective measures, which are applicable particularly to California conditions.

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[1] Grateful acknowledgment is extended to the many persons who, by their encouragement, suggestions, or actual services, have contributed to the development of this work since its inception. In particular, acknowledgment of indebtedness is due to D. M. Ilch, junior forester, and E. W. Kramer, Jr., engineer-foreman, for their efforts in developing improvements in the technic of road-erosion control in the course of large-scale operations under their supervision on forest highways; and to E. W. Kramer, Sr., regional engineer, for his active cooperation in making these large-scale projects possible.

THE EROSION PROBLEM ON MOUNTAIN ROADS

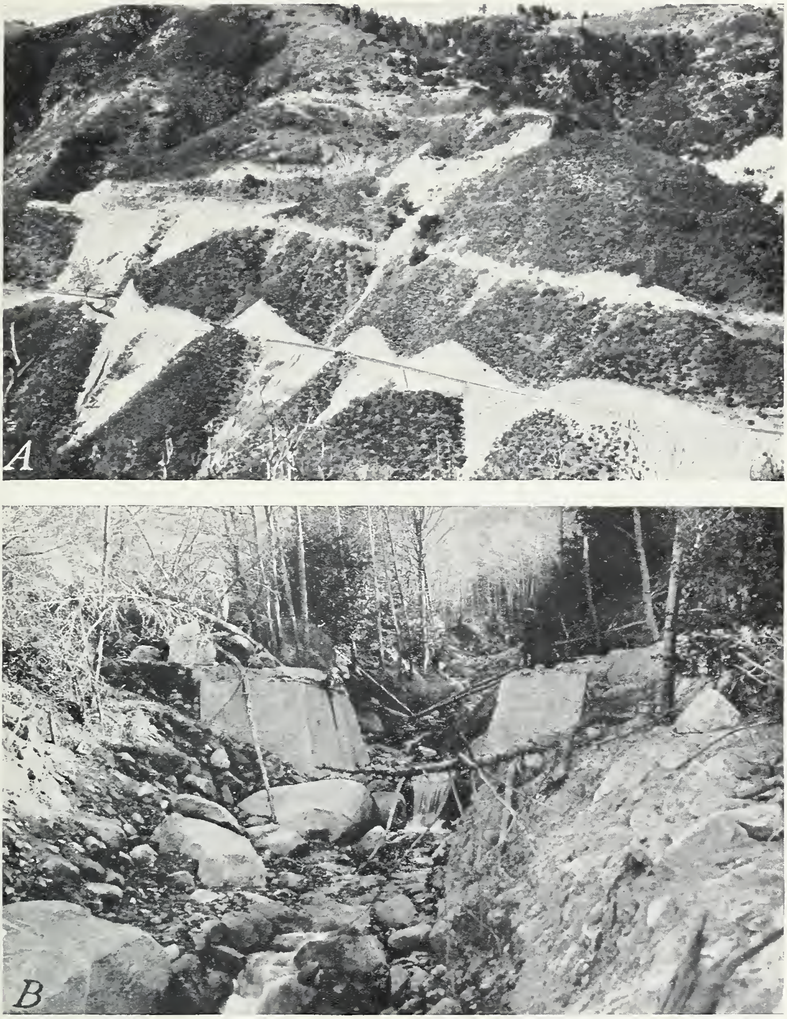
No sooner is a new road constructed than the forces of nature are at work to destroy it. Water and wind, cold and heat, and the constant pull of gravity, all combine to break up the road surface, tear down the fills, and round off the squared edges of shoulder berms and back-slopes—in short, to eradicate the entire road and cause the area occupied by it to revert to the wild state. On newly improved roads the wear by traffic is unimportant compared with the work of these natural forces, and of these forces the most powerful by far is water (pl. 2, *B*).

The destructive action of water is especially rapid on mountain roads, where the area of erosible fill slopes is not only necessarily large but is often needlessly exposed to the concentrated run-off from the impervious road surface. For several years following the construction of such roads it is a common experience to find them after each heavy rain "TEMPORARILY BLOCKED" by slides from cut slopes, and to see great gullies carved into fill slopes by the escape of road-surface water over broken shoulder berms (pl. 3, *A*).

Maintenance departments usually make the best of such bad situations by using the slides to fill gullies and to restore the road to grade at washouts; but the thoughtful observer, looking beyond the immediate gullies, may see other more extensive consequences which cannot be so easily rectified (pls. 2, *B* and 3, *B*). The damage below a storm-gullied road, though sometimes less conspicuous, is often much greater than that to the road itself and, what is more serious, this accessory damage is frequently of such a nature that it can never be repaired.

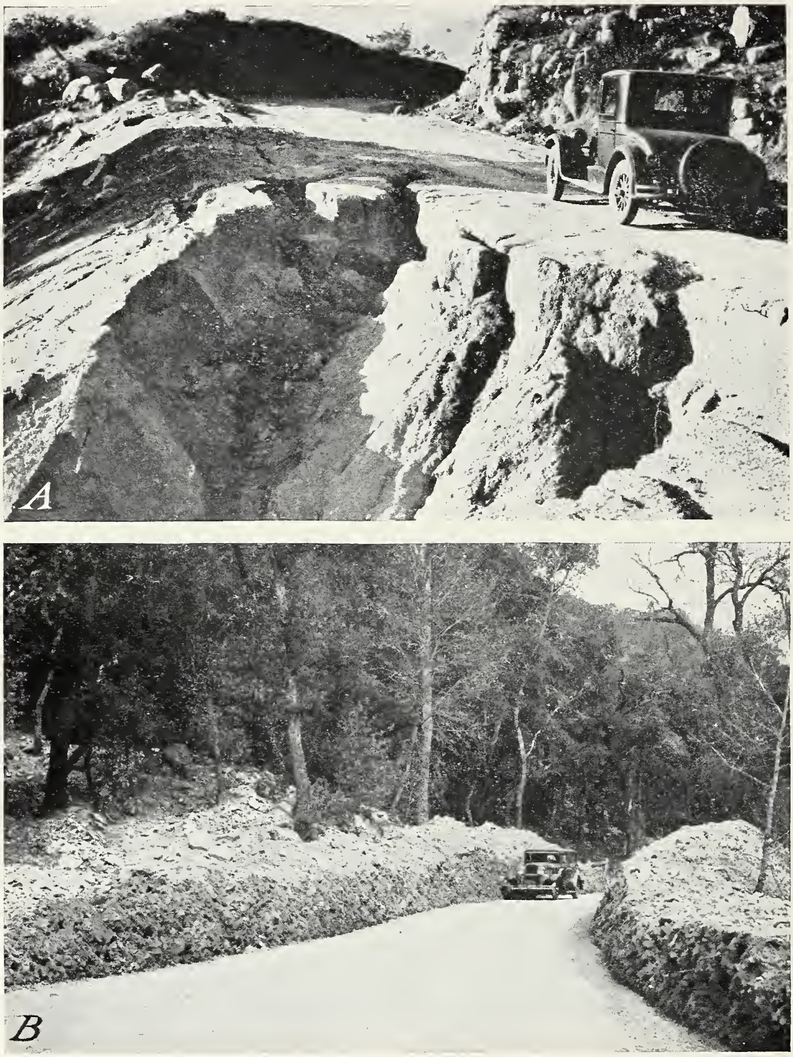
The direct cause of all this damage is, of course, the movement of enormous quantities of soil and rock which are loosened during construction and started on a suddenly accelerated descent to the sea. A great part of this displaced material finds its way almost immediately into stream channels, reservoirs, water-spreading grounds, and irrigation works. The damage to water supplies created by such deposits has in some localities reached serious proportions (pl. 4, *A*). Recreational values are similarly hard hit, in the extermination of fish in pools filled by the eroded silt and sand, in the destruction of camp grounds, in the despoliation of streamside beauty by mud and boulder flows, and in damage to roads and bridges. Agricultural lands are encroached upon and sometimes ruined. Mountain cabins and even suburban homes are damaged and their sites impaired in value by heavy deposits of erosion debris (pl. 4, *B*). Specific instances of damage from road erosion are cited in the appendix.

In southern California, especially, the extremely steep slopes, torrential winter rains, and intensive recreational development in the mountain areas have combined to invite extraordinary damage of this sort, but the situation is paralleled to some degree on new roads in high mountains elsewhere. The consequent losses in terms of private property, public improvements, human welfare, and higher taxes it would be impossible to estimate. The important considerations are: (1) That the total impairment in any affected community is sufficiently great to demand immediate improvement, and (2) that these damaging and dangerous conditions are by no means incur-



RESULTS FROM CONSTRUCTION OF A NEW MOUNTAIN HIGHWAY.

A, Note the great increase in area of cut and fill slopes in the new road (foreground) as compared with those of the old road above it. Gullies are already developing in the overcast slopes of this new high-gear road in the Waterman Canyon section, Rim-of-the-World Drive, San Bernardino National Forest, Calif. *B*, Erosion debris came down with heavy rains in a torrential flood causing severe damage in the canyon bottom. The concrete masses are abutments of a bridge three times carried away by similar floods. The huge boulders brought down, the gutted creek bed, and the wreckage of trees bear witness to the enormous power of the flood.



A, Newly built road rendered almost impassable by erosion through lack of surface drainage. A well-built shoulder berm and adequate culvert would have prevented this dangerous and costly washout. (County section of Mill Creek Forest Highway, San Bernardino Mountains, Calif.) *B*, Debris 7 to 20 feet deep deposited on lower Arroyo Seco Road by erosion from new road above (Angeles Crest Highway shown in plate 1), destroying a charming roadside picnic spot at left. Keeping this canyon road open in rainy weather will for several years be a recurrent problem. (Angeles National Forest.)

able, but may be largely if not wholly removed through the development of preventive and corrective measures without unreasonable increase in costs. The introduction of such measures becomes therefore a matter of general public interest.

PREVENTIVE MEASURES

At the outset it must be recognized that the ideal, from the standpoint of erosion prevention, cannot be attained in mountain roads because of the clash of divergent objectives. On the one hand is the necessity to build more and bigger roads to accommodate the increased travel to the mountains. On the other hand is strenuous objection to the scenic disfigurement caused by such roads on the part of a large and articulate section of the public which is becoming increasingly aware of the scenic, inspirational, and recreational assets of mountain and forest. Further objection comes from agencies and individuals whose property or interests are injured by erosion from the new high-standard roads.

Highway engineers, aware that the motoring public has doubled its ordinary travel speed in the past 10 years and that the increase in the volume of mountain-bound traffic has been still greater [2] in that time, must naturally be opposed to any reduction in standards of alinement, width, and gradient, for in these features lie the principal means of meeting the pressure of ever greater speed and volume of traffic. Inasmuch as the most effective way to minimize scenic disturbance and erosion is to fit road alinement to topography, it is chiefly over this point that compromise must be effected. In some sections it is particularly difficult to reconcile the public demand for fast roads with the public sentiment for scenery.

Since this publication is intended chiefly to present methods of checking erosion on existing roads, it may appear presumptuous to discuss preventive measures which in this case are largely, if not wholly, engineering problems. However, since erosion-control measures are often rendered ineffective and their cost is greatly increased under present methods of construction, the discussion of preventive measures appears justified. For the most part these measures are relatively simple modifications of certain features of design and construction. Objection will undoubtedly be made to their cost, but they are nevertheless proposed as effective and indispensable means to ends that amply justify such costs.

NEW CRITERIA OF LOCATION

In the modern forest highway the strictly commercial criteria of minimum grade and curvature over the shortest practicable route at lowest construction cost should not be permitted to dictate location. Most mountain highways are largely recreation roads, and their function in revealing the scenic beauties of the country they traverse merits as much consideration as does that of giving access to some distant hinterland. From this viewpoint, the ideal mountain road is not necessarily the shortest route; it may be one that, though longer, will be less conspicuous from the valley or from an opposite slope, and one that will require less excavation, and at inconspicuous points. The well-built road should have in some degree the appearance of having been fitted into the landscape rather than chopped and blasted out of it. Lack of such consideration is evident in the views shown in plates 1 and 2.

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[2] According to the Forest Service count of persons entering the national forests in California the increase in that State has been 500 percent.

Especially to be avoided is the building of two or more roads between the same two points on the same general slope. This is sometimes done to avoid excessive grades or curvature of the old road, but occasionally for no other reason than to permit use of the old road for a detour during construction of the new. This practice, while permissible and not too harmful in a level valley, invites too much disfigurement and damage to be allowed in the mountains. Wherever possible the new road should follow the route of the existing road, if by such action extreme disfigurement and excessive movement of material can be avoided. Occasional stretches of gradient considerably above the standard adopted for the new road do not constitute serious obstacles for modern motor vehicles.

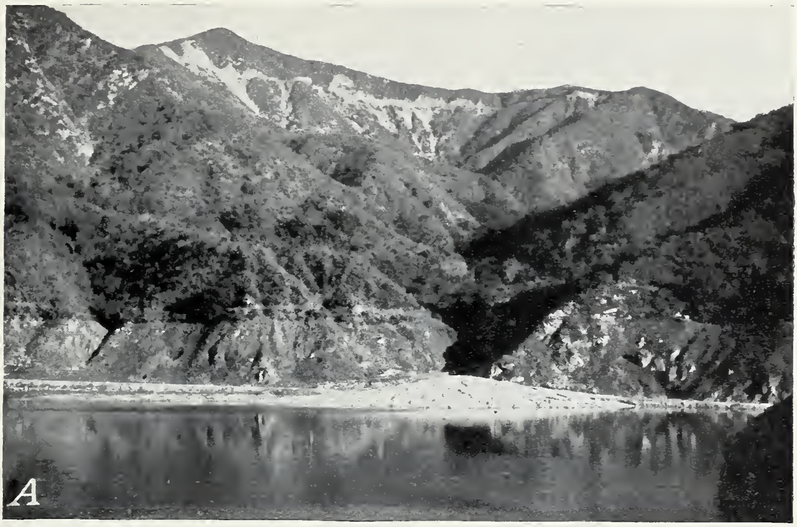
MORE RATIONAL ALINEMENT

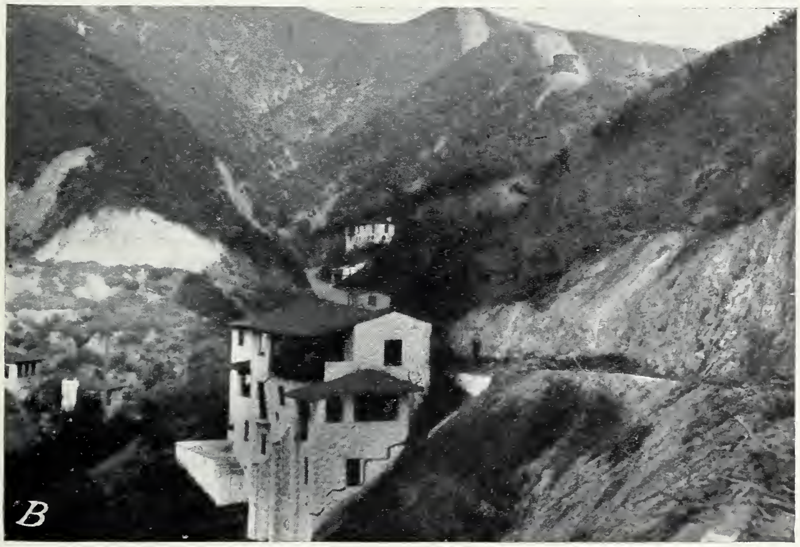
The great majority of the public can be educated to accept a slower travel speed on mountain roads than on valley highways. A greater curvature than at present, both horizontal and vertical, resulting in less cut and fill, can be employed on all save the few major mountain roads which are links in national highways or which carry heavy traffic between large cities. With a more " natural " curvature, long tangents should give way to careful efforts to leave nature undisturbed wherever and to whatever extent possible. While the primary purpose here is to reduce the volume of rock and earth which is loosened and rendered unstable, the safeguarding of scenic value is equally desirable. Even on such roads as the new ridge route cut-off in U S 99 or the Waterman Canyon section of the Rim-of-the-World Drive (both in California), initial cost is so high that provision for erosion prevention could have been, and on future similar projects can be, included in the original plans at a relatively moderate additional cost.

GREATER USE OF RETAINING WALLS AND CRIBBING

Ordinarily retaining walls and cribbing are used only where they are absolutely necessary to restrain slides on the upper side of the road or to support shoulders on excessively steep lower slopes, or where the toe of a fill reaches a stream or another road at a lower level. A more liberal use should be made of walls of native rock on minor roads, and of cribbing of concrete or metal on major roads, for the express purpose of reducing the volume of both cuts and fills.

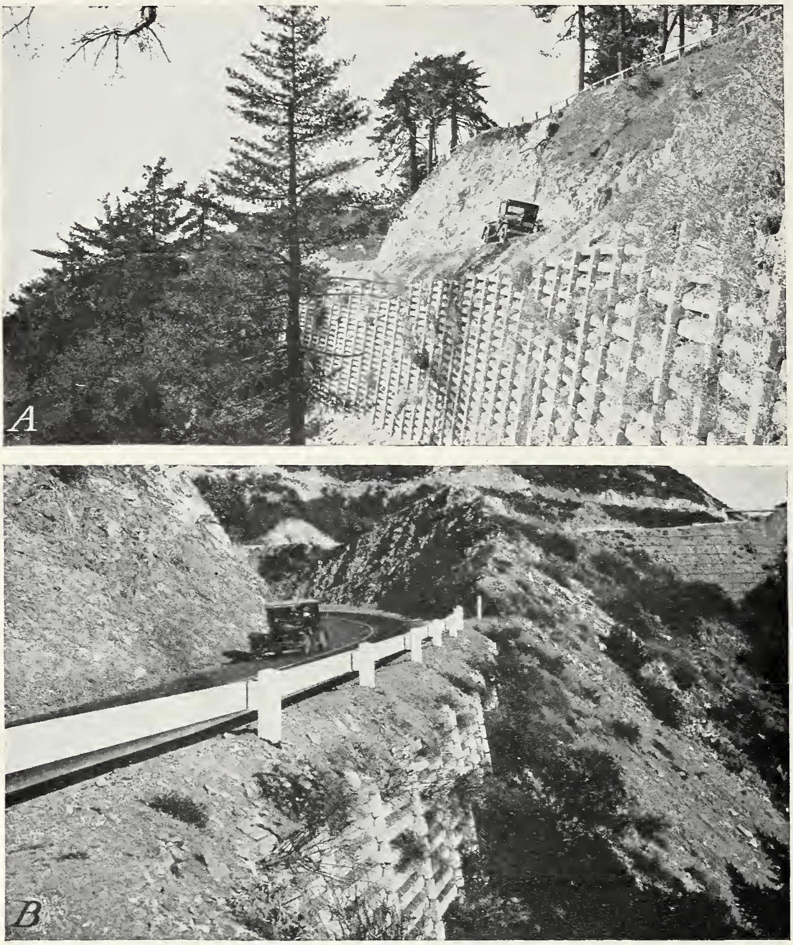
On slopes too steep to hold overcast material, the common practice of cutting a " full-bench " section to carry the entire width of the road requires the excavation of much material. If overcast, this material destroys the down-slope vegetation, leaving a bad scar and often causing additional damages as previously described; if it must be end-hauled any considerable distance to a more favorable waste area other than a fill, it increases the cost of the cut. In such cases





SEVERE EROSION DAMAGE FAR BELOW THE MOUNTAIN ROAD.

A, Delta formed by erosion debris from road shown high on distant slope, containing upwards of 8,000 cubic yards of material. Additional deposits along creek continue to move down into reservoir during heavy rains. (Glendora Mountain Road and Pine Canyon Reservoir of the city of Pasadena, Calif., San Gabriel watershed.) *B*, House ruined and almost pushed from foundations by earth slide from a road higher up the slope of this suburban subdivision. Tons of earth crashed through the upper floors of the house. Note cracks in side wall and in front at corner of top-floor porch.



EFFECTIVE USE OF CRIBBING.

Depth of cut is reduced and natural appearance of mountain slope preserved in the Arrowhead Highlands section, Rim-of-the-World Drive, San Bernardino National Forest, built by the United States Bureau of Public Roads. *A*, Precast, interlocking cribbing on a steep slope protects trees, which in turn screen structure and support slope below road. *B*, Small crib permits completion of a good curve with minimum cut; native vegetation growing between headers aids in concealing structure.

the proper use of cribbing to support up to one-third of the road width would limit the overcast material to the small excavation necessary for crib foundation, since the crib would carry all or nearly all of the material excavated for the reduced bench width, as shown in figure 1.

It is believed that the prevention of damage below the road and the resulting gains in road permanence and lowered maintenance costs will go far towards balancing the additional cost of the cribbing, even if the preservation of landscape beauty is left out of consideration (pl. 5).

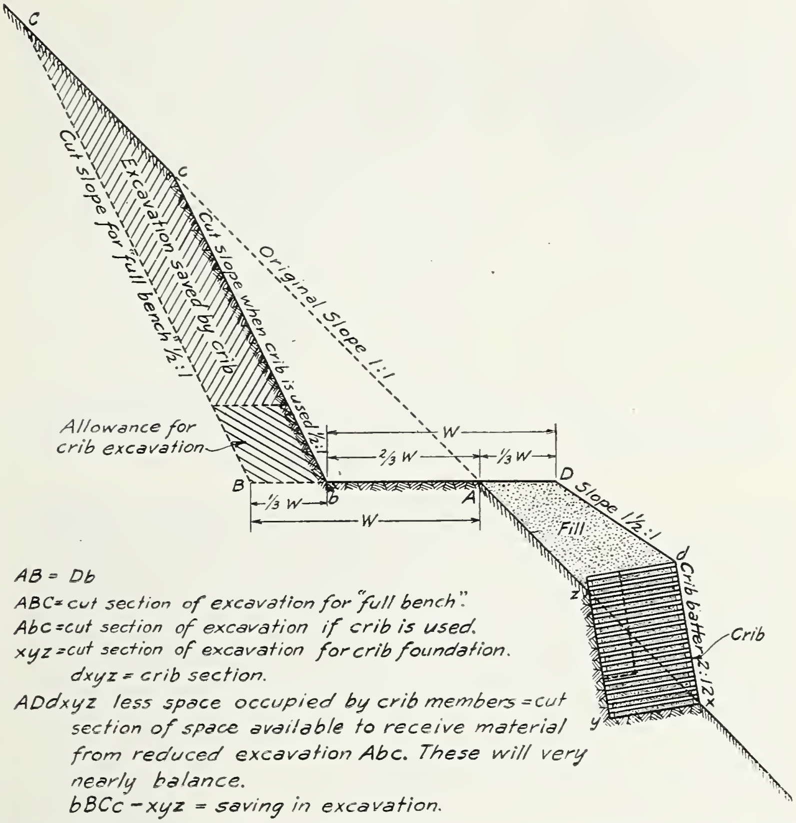

C
c
Cut slope for "full bench" ½:1
Excavation saved by crib
Cut slope when crib is used ½:1
Original Slope 1:1
Allowance for crib excavation
W
⅔ W
⅓ W
D
Slope 1½:1
B
b
A
⅓ W
W
Fill
d
z
Crib batter 2:12
x
Crib
y
AB = Db
ABC = cut section of excavation for "full bench".
Abc = cut section of excavation if crib is used.
xyz = cut section of excavation for crib foundation.
dxyz = crib section.
ADdxyz less space occupied by crib members = cut section of space available to receive material from reduced excavation Abc. These will very nearly balance.
bBCc − xyz = saving in excavation.

FIGURE 1.—Illustration of the very considerable reduction in excavation made possible on a steep slope by the use of cribbing. Crib proportions shown are suitable for log construction; if crib were built of concrete or steel, shorter spreaders could be used in upper 11 feet as indicated by the dash line.

CONTROLLED PLACEMENT OF EXCESS MATERIAL

A large share of the damage caused by mountain roads comes from the erosion of unavoidably excess material, both that necessarily excavated during construction and that brought down by unpredictable slides. On construction jobs where this material is not needed on the road, little or no effort is made to hold it. After a road is completed, sloughing of cut slopes is the chief source of such material. While it is obviously impossible, even if economically permissible, to anchor every cubic yard of excess material in a place where it cannot erode, yet the prevention of damage is justification for considerable effort in this direction. Just how this can best be done is a problem for special duty on each project.

An excellent method[3] is to place the material in the natural basins formed upstream by through fills, with proper attention to drainage to prevent overflow from the watershed above. In deep basins of this type, the use of drop-inlet culverts permits the gradual raising of the inlet, until the basin is filled with detritus to maximum capacity (fig. 2). The basins thus act as debris-storage reservoirs and the material once deposited therein is permanently disposed of. If full advantage is taken of such opportunities on mountain roads an enormous yardage of material can be withdrawn from destructive progression seawards. The basins, moreover, offer an excellent solution to the problem of harmless disposal of slides, and in anticipation of such use the basins in proximity to deep cuts can be left empty during construction for this purpose. Many such basins, when filled to capacity, can be developed into attractive parking or picnic areas for use during the dry season. Their utility for this purpose may be enhanced at slight expense by the development of a water supply for public use (pl. 6).

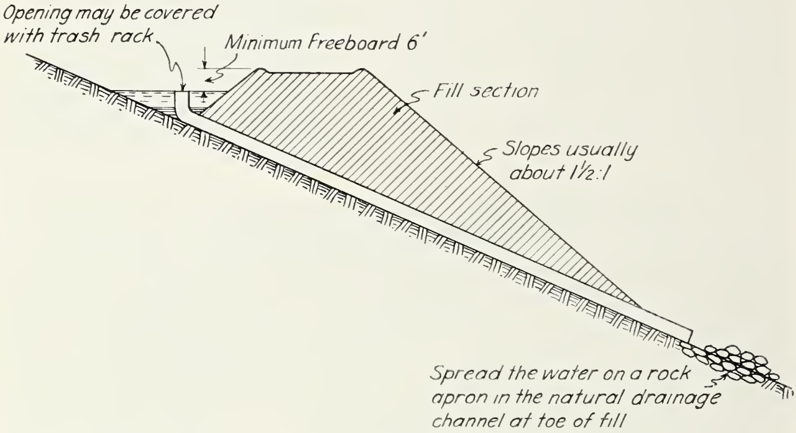

Opening may be covered with trash rack
Minimum Freeboard 6'
Fill section
Slopes usually about 1½:1
Spread the water on a rock apron in the natural drainage channel at toe of fill

FIGURE 2.—Drop-inlet culvert, converting the basin above a through fill into a debris-storage reservoir.

On gentle slopes (less than 1½ to 1) natural amphitheaters below inside curves of the road can be filled and ultimately used as parking areas. Enormous quantities of material can be disposed of in this way, and when the fills are completed their outer slopes can be controlled and planted in the manner described later for fill slopes. A final dressing of the slope with topsoil withheld for the purpose will hasten and improve the plant cover. Toe walls or cribbing can be used in connection with these basins to increase their volume capacity within desired areas. The largest item of expense for such

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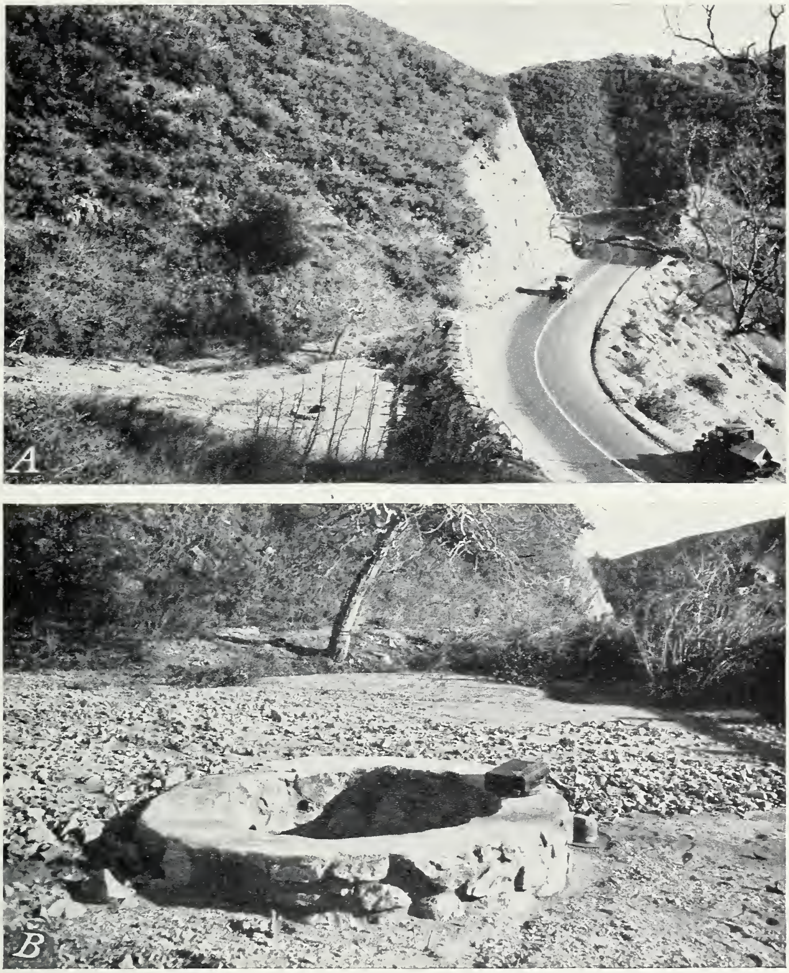
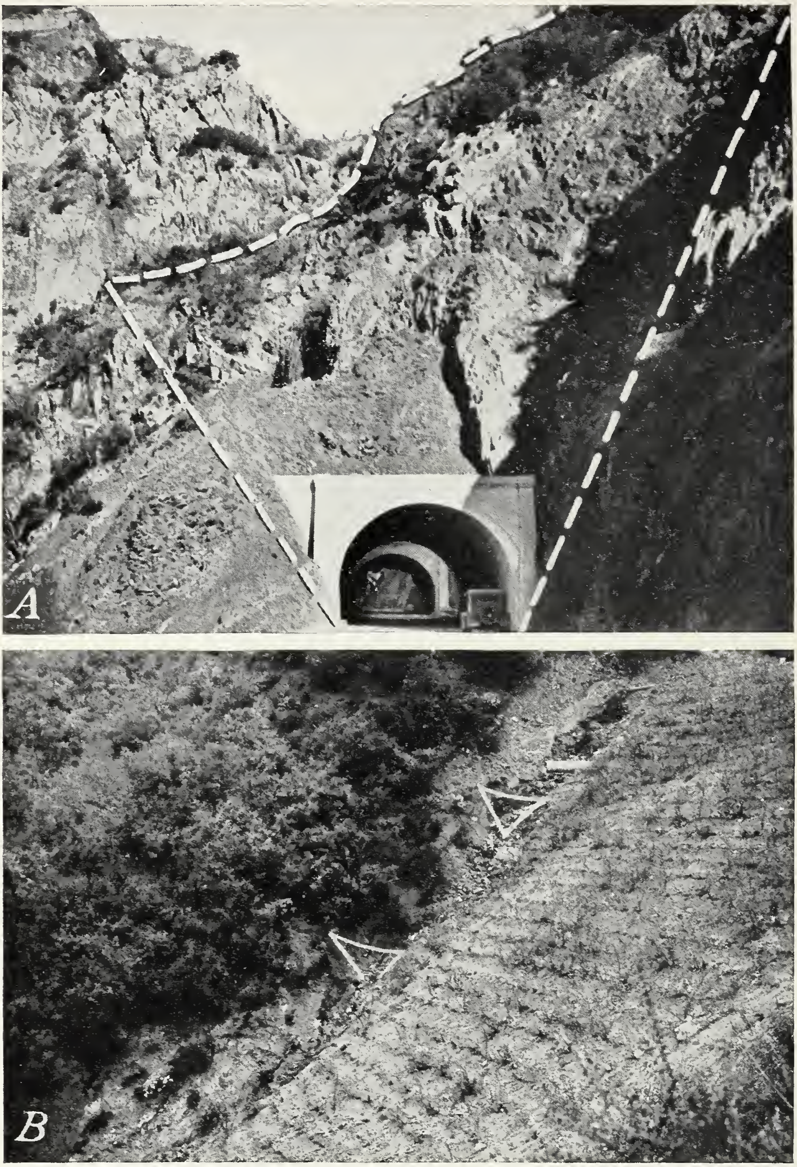
[3] Employed on the lower section, Angeles Crest Highway, Angeles National Forest, by California State Division of Highways, S. V. Cortelyou, district engineer, A. M. George, resident engineer.



DROP-INLET CULVERT WITH INTAKE BUILT IN BASIN ABOVE THROUGH-FILL.

A, Road fill here acts as dam, impounding debris washed down from fills at higher levels. *B*, Tiles set in well wall permit complete drainage of basin and prevent formation of stagnant pool below rim of well curb. (Waterman Canyon Road, San Bernardino National Forest.)



A, Tunnels greatly reduce volume of excavation, permitting more direct alinement of road and avoiding excessive disfigurement of mountainside. Dotted lines indicate enormous amount of material to be removed if through-cut had been used instead of tunnel. (Ventura-Maricopa Highway, Santa Barbara National Forest.) *B*, Culvert (upper right) improperly emptying at side of fill, cutting treated slope seriously and threatening large-scale slump by undercut at toe of slope; should be carried down to foot of slope to empty on rock talus, or prepared rubble basin. Wattled slope has withstood 12-inch rainfall, but could not withstand concentrated flow from culvert.

controlled disposal of excess material will be for hauling, together with a small amount for the necessary additional culvert.

Other though less desirable methods of disposal, where walls or cribs cannot be provided but where the topography is favorable, are: (1) To haul the excess material to a gentle slope well covered with vegetation and distribute it along the shallow fill where the cover will prevent its movement and will gradually aid in clothing the new slope; (2) to dump all excess at a minimum number of carefully selected waste stations such as natural rock slides or slopes terminating in flats upon which the talus cone can be held and overgrown. A final dressing of saved topsoil over the rock-slide dump will assist the development of at least a partial cover of herbs and small shrubs.

TUNNELS AND BRIDGES

In keeping with items (1) and (2) above, the use of occasional tunnels, where rock structure permits, in place of extremely deep through cuts, and bridges in place of large through fills, is logical and desirable. The deeper the cut the greater the displacement of earth and the greater the danger of slides and gully erosion.

It is appreciated that tunnels and bridges are the most costly items of road construction, and that to suggest increasing their number is to invite severe criticism of the entire plan as impracticable. Moreover, where the rock is highly fractured or soft, as in southern California, tunnel costs are greatly increased because of the concrete lining required for safety. Yet it is in precisely such places that deep through cuts give the most trouble from slides, either during construction, compelling much extra-quantity excavation, or after the road is completed, causing traffic hazards and delays and heavy maintenance expense.

Here again high initial cost may be largely balanced in the long run by the elimination of destructive possibilities (pl. 7, *A*). In addition, the element of surprise and charm given a mountain road by judiciously placed tunnels, particularly (but not necessarily) if they can be windowed, is a source of great pleasure to motorists. Indeed, on high-standard recreation roads the luxury of tunnels and attractive bridges will usually be found to have the enthusiastic approval of the public.

IMPROVED DRAINAGE PRACTICE

Improved drainage is vital to the whole problem of road maintenance and erosion prevention. Experience of the past several years has shown clearly that previous standards of drainage are inadequate on mountain highways and that more and better drainage is needed. Considerable advances have been made but on most projects the situation is still far from satisfactory. On practically every mountain road that has been built or widened within the past 10 years there will be found numerous instances of active accelerated erosion caused by inadequate drainage. Although drainage is properly a phase of construction, this situation requires that drainage improvement be considered as the first step in erosion control. This subject is, therefore, discussed in greater detail under the heading of control measures.

These six features, presented as erosion-preventive measures that can be observed in the course of construction, appear fundamental to the broader concept of mountain roads, not as traffic arteries pure and simple, but as scenic and conservational assets. This concept involves taking the long-range view of the road and all its effects, charging the road with the actual attendant damages it will cause, and setting high value upon the intangible item of landscape beauty.

In the case of the many purely recreational roads, or of those within sight of populous communities, the preservation of scenic values alone would justify the increased cost, in the opinion of many persons qualified to judge. Nor is this added cost necessarily to be regarded as an insuperable obstacle to the building of better mountain roads. Present costs per mile for road building have reached figures that would have seemed fantastic 10 years ago; and yet these costs, forced by the great growth in motor traffic, have been easily paid for by that same traffic. It is not unreasonable to assume that the cost of the improvements suggested above for mountain highways can be met in the same way.

CONTROL MEASURES ON EXISTING ROADS

Even though the preventive measures outlined above were to be immediately accepted and put into practice on all new roads, there would still be in mountainous areas a large mileage of high-standard roads which were built, or are even now under construction, without sufficient regard to their erosion and scenic-defacement potentialities. On all these roads something must be done to prevent or minimize the damage of which they are capable. The control measures described here have been developed during the past several years by the California Forest and Range Experiment Station and have been tried out extensively and proved successful under a variety of conditions. It is not implied that these methods constitute the last word on control of erosion on mountain roads. They are the best achievement to date and, under average conditions, will be efficacious. They are not universally applicable without modification, however, and in their application judgment must be exercised to adapt them to the variable conditions found on the different slopes.

The corrective or countererosion action which can be taken falls into two broad divisions, namely, improvement of drainage and stabilization of the slopes by revegetation. These should be undertaken in the order named, since without proper drainage all other corrective work may be rendered useless.

DRAINAGE IMPROVEMENT

It is not the purpose of this circular to discuss the general principles of road drainage,[4] but rather to suggest a few necessary extensions or improvements with the specific objective of reducing

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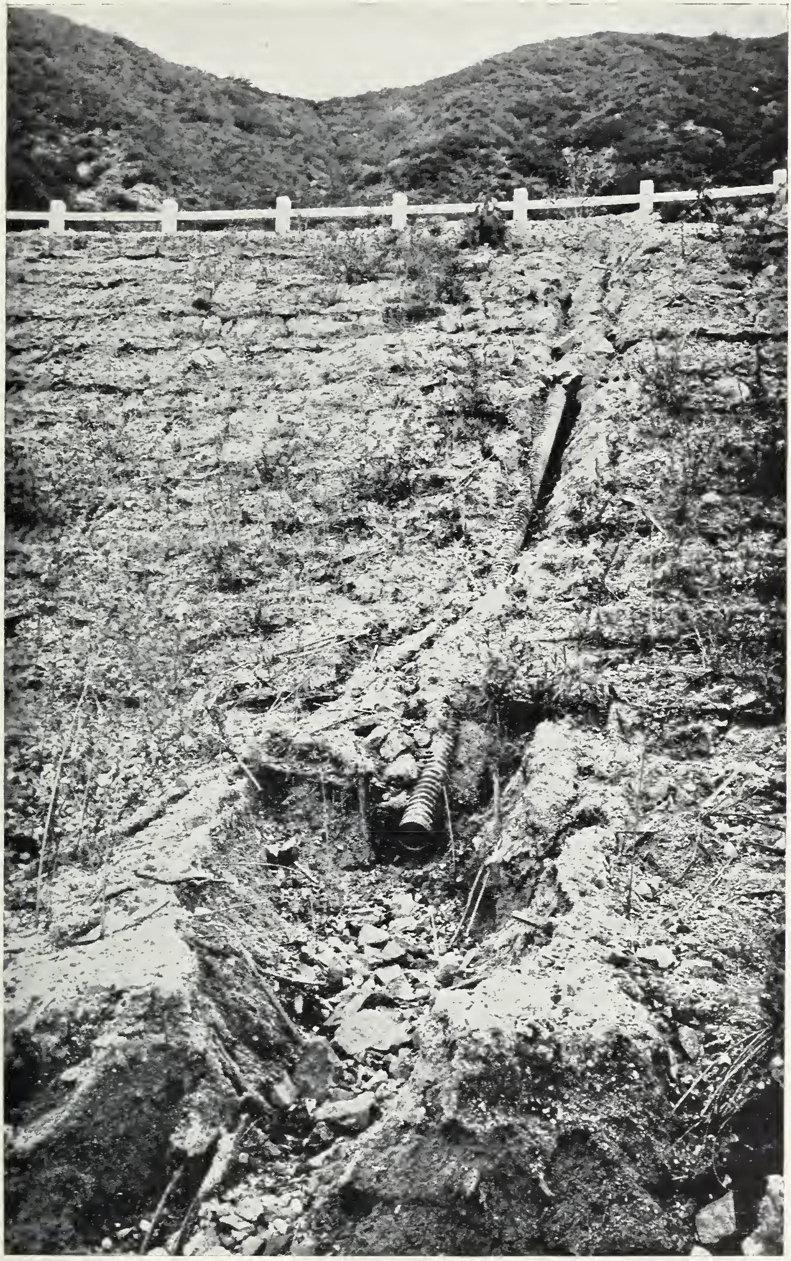
[4] For detailed treatment of road drainage, the reader is referred to standard engineering textbooks on the subject, such as the following:

BRUCE, A. G. HIGHWAY DESIGN AND CONSTRUCTION. 628 pp., illus. Scranton, Pa. 1934. See ch. 5.

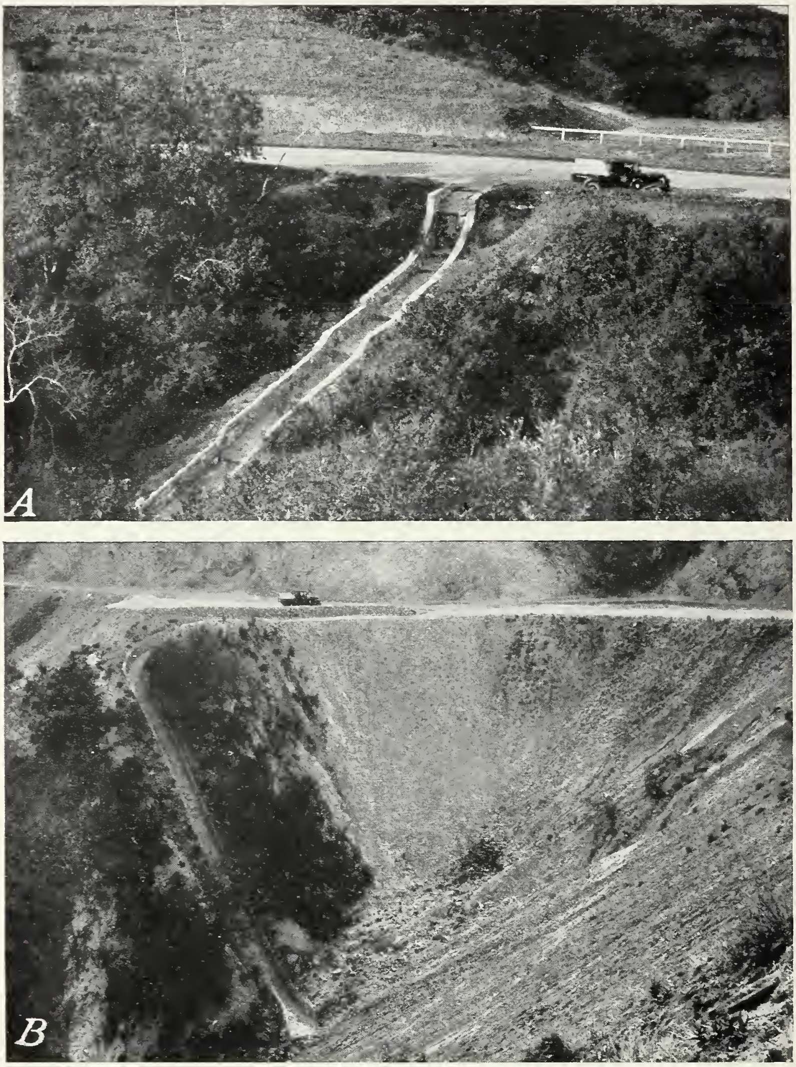
BATEMAN, J. H. HIGHWAY ENGINEERING; A TEXTBOOK FOR STUDENTS OF CIVIL ENGINEERING. Ed. 2. 441 pp., illus. New York and London. 1934. See ch. 5.

JAMES, E. W., PEIRCE, V. M., and MOOREFIELD, C. H. DRAINAGE METHODS AND FOUNDATIONS FOR COUNTY ROADS. U. S. Dept. Agr. Bull. 724, 86 pp., illus. 1918.



DRAINAGE CONTROL THAT FAILED.

Well-intentioned but inadequate effort to correct road surface drainage that had already overflowed the berm and gullied the wattled slope; the culvert inlet, too small, clogged and overflowed again; the pipe emptying half-way down slope gullied the remainder of the slope. A sufficient inlet and extension of pipe to foot of slope, together with firm backfill around pipe, are required.



SURFACE DRAINAGE PROPERLY CARED FOR.

A, Outlet and spillway of well-built rubble masonry construction carrying water down to natural channel. *B*, Flume, also of rubble masonry, with a grated intake of ample capacity and outfall on rock talus, the latter appearing to require reinforcement to prevent undercutting (Griffith Park, Los Angeles.)

erosion. It is not overstating the case to say that inadequate and faulty drainage, rather than local peculiarities of soil or weather, is responsible for most of the serious erosion of mountain roads. Among the principal contributory features are the following:

CULVERTS EMPTYING AT IMPROPER POINTS; OUTFALL POINTS NOT PROTECTED AGAINST UNDERCUTTING

The most destructive practice on minor roads, but also frequently observed on highways, is the emptying of pipe culverts upon the middle or down one edge of highly erosible fill slopes with resultant gouging out of huge gullies or serious side cutting of the slopes (pls. 7, *B* and 8). Emptying the culverts upon adjacent brush-covered slopes is almost equally destructive where the soil, in spite of its vegetative cover, is susceptible to deep erosion from the concentrated run-off. Gutter turnouts or spillways through the road shoulder, if placed anywhere except on firm rocky slopes, cause serious gully erosion, as already shown in plate 3, *A*.

Correction.—Where channels cannot be reached directly, the structures should be extended to solid rock ledges from which the water can reach natural channels over rock all the way, or the water should be flumed down the slopes to empty upon rock talus at a point where this is firm enough to resist erosion. Metal half-culverts can often be used for this purpose at not excessive cost. Plate 9 shows two excellent types of rubble masonry flumes which constitute positive insurance against erosion damage from road-surface drainage. Where culverts must of necessity terminate upon erosible material, adequate outfall aprons of heavy riprap, or basins of rubble masonry, concrete, or even of logs, should be built to prevent gouging. Dense planting of willow or baccharis cuttings for a considerable distance around the outfall will give a strong natural reinforcement to the structure. Lack of such provision at drainage outlets has been one of the most serious shortcomings of highway-drainage practice.

DRAINAGE OUTLETS FROM ROAD SURFACE TOO FEW, OR NOT PROPERLY PLACED

Results of these conditions include erosion of ditches, side-cutting of shoulder berms, and final failure of the berms, permitting escape of uncontrolled water over the road slope. Lack of drainage is especially serious at the low points of inside curves on fills. Such undrained low spots sometimes result from settlement of the fills, but they have also been observed as a result of adverse grades on curves of newly completed roads. During heavy rains a pool forms behind the shoulder berm at the low point and finally pours over, cutting a notch in the berm and a deep gully in the fill slope.

Correction.—The more numerous the outlets for taking water off the road surface, the less the accumulated water in the ditches and the smaller the volume turned out at any one point and consequently the less the total erosive power of the water. Careful inspection following heavy rains on a new road will indicate the points requiring attention. In the case of the inside curves mentioned, the adverse grade may be eliminated, permitting water to reach a proper drain away from the fill. If this cannot be done, a culvert should be installed carrying the water back under the road to empty in the main culvert basin on the upper side. If there is no such basin and the culvert is led through the shoulder on the lower side, the culvert outlet should be handled as described in the preceding section.

DRAINAGE OUTLETS TOO SMALL FOR HIGH-INTENSITY STORMS

On occasional stretches of road which offer limited opportunity for drainage outlets, the culverts actually installed may be too small to accommodate the run-off from high-intensity storms. In such cases the use of large-sized culverts, although at greater initial cost, is justified to forestall damage and repairs which together may cost many times the increased culvert expense. Moreover, pipe culverts as small as 12 inches in diameter are often clogged by storm trash. It appears likely that under California conditions the minimum diameter of pipe culverts for mountain roads may well be set at 16 or 18 inches.

BLOCKING OF DRAINAGE BY SLIDES IN THROUGH CUTS

Water from upgrade accumulates in the road above the slide until it pours over the shoulder berm, causing a gully or a serious washout, depending on the volume of water. Such slides cannot always be anticipated, but the washouts can be prevented by installation of adequate drainage structures on the upgrade side of all deep through cuts at a point where they cannot be choked by possible slides.

THE MENACE OF MINOR ROADS

The significance of minor roads and truck trails, from the standpoint of erosion, is evident from the enormous mileage of this class that has been built of late in the national forests and other mountainous districts by the Civilian Conservation Corps and other emergency organizations. By their very nature such projects have invited concentration on mileage, with scant attention to such refinements as finish and drainage. Often the pursuit of economy has gone beyond the irreducible minimum of drainage and as a result some national forests now find themselves faced with a major erosion problem (pl. 10, *A*).

The method of out-slope construction, in which the entire road is given a slight pitch toward the outer shoulder to permit continuous run-off laterally from the surface, does not appear well adapted to this area.[5] Shoulders settle and wear rapidly during heavy rains. Despite all efforts to build and maintain uniform outward slopes, water nevertheless accumulates and runs down the axis of the road to some obstruction or slight depression where it pours out with sufficient force to cut a troublesome gully. In a short time the outer wheel track is badly corrugated by such gullies, which at their worst may cut back far enough to make the out-slope road dangerous, if not completely impassable.

The fact must be faced that these minor roads have large potentialities for erosion damage and that the only solution is carefully planned drainage. Such drainage, moreover, will require the same safeguards and precautions demanded on major roads, although their construction can naturally be lighter and simpler. The conclusion appears inescapable that it may be better to build 9 miles of permanent dependable road than 10 miles which may be put out of commission by a heavy rain and may have to be practically rebuilt every spring.

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[5] Application of the out-slope principle requires further study. It has been observed to function satisfactorily on the Sierra National Forest, Calif., where the local vegetation not only controlled the run-off but by rapid invasion upon the road itself protected the shoulders against serious erosion.

ABANDONED ROADS

Stretches of old road, abandoned in consequence of the building of a new and better road, have proved potent sources of erosion, often seriously damaging the new roads. For such outmoded roads a choice of treatments should be made: (1) If the old stretch is to be continued in use as an emergency way, it should be properly drained whether it is otherwise maintained or not; (2) if it is no longer needed, it should be made erosion-proof or completely eradicated by plowing and planting or sowing with appropriate native tree and shrub species (pl. 10, *B*).

TREATMENT OF FILL SLOPES

Assuming that road-surface drainage has been satisfactorily provided for, the fill slopes will require protection only against excessive wearing by wind, gravity, and the rain which falls directly upon them. In its simplest terms this treatment comprises four steps: (1) Preparing the slope by smoothing existing gullies and combing down loose rock; (2) mechanical anchorage of the slope surface by a system of contour trenching, imbedded wattling and staking, in various combinations and spacings best suited to local soil conditions; (3) the sowing of cereal grains or other quick-growing annuals to gain the rapid soil-binding benefit of the fibrous roots of this temporary vegetation; and finally (4) the planting of suitable trees and shrubs, including cuttings of willow, water motie (*Baccharis* spp.), elderberry, and other sprouting species, to establish a complete self-perpetuating cover of vegetation on the slope and thus make the soil control permanent.

SMOOTHING THE SLOPES

The purpose of this operation is twofold—to eradicate gullies which might have been formed before the work was undertaken and to bear down from the surface all loose rock which will either interfere with the work or which, if left on the slope, might later roll down and disturb the completed work. This operation is begun at the top of the slope with a crew of men spread out on the contour and working down gradually. Ordinarily mattocks are the only tools needed for this work, but occasionally bars will be required to remove especially large rocks. In some situations it may be feasible to use machinery, such as tractors or draglines, to reduce the amount of hand labor necessary. In planning for the use of machines, however, it must be borne in mind that the natural vegetation at both ends of the fills must not be ruthlessly broken down by the placing of a tractor or hoist engine, such as would be necessary for the operation of a cross-haul dragline. On gentle slopes the adjacent vegetation can be disturbed to a slight degree without serious results, but this should not be permitted to go far enough to start fresh erosion.

In working slopes which have been badly eroded before control is begun, it is not possible to eliminate the very large and deep gullies. In such cases the sharp intergully ridges should be rounded off to a curvature flat enough to permit the installation of contour wattles.

The combing operation should be done only far enough ahead of the wattling to avoid hampering the wattling crew. If several slopes are combed before wattling, particularly during the rainy season, there is danger that a heavy storm may again erode the smoothed slopes and cause the work to have to be done over (pl. 11, *A*).

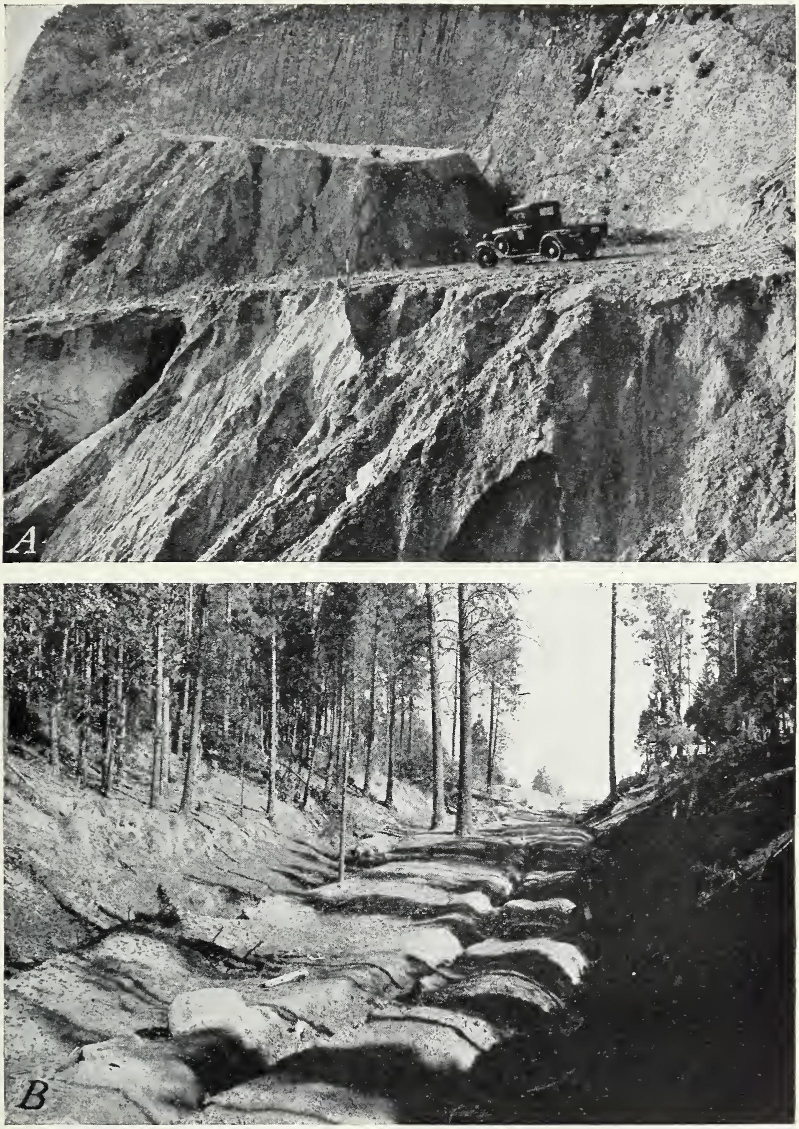
Occasionally a very large boulder or rock, lodged high on a filled slope and insecurely bedded, remains after construction of the road, owing to the absence of any requirement for removal in the construction specifications. To facilitate the movement of such a rock, and to prevent excessive danger and damage from starting it downhill in one piece, it should first be broken into smaller fragments. With hard rock, such as granite and diorite, this may best be done by the use of dynamite applied to the surface under a mud pack. This method is equivalent to striking the rock with a giant hammer, fracturing it downward rather than scattering it widely in fragments. This method of breaking boulders is useful also in preparing material for rubble or dry rock walls.

When combing slopes which extend to other roads at lower levels, to camp grounds, cultivated land, or other property likely to be damaged, it will be necessary to prevent excessive rolling or scattering of the rocks at the foot of the slope by laying up a dry rock wall, erecting a barrier of logs, or simply piling a large windrow of cut brush across the foot of the slope at a point at which the leaping rocks cannot overtop it (pl. 11, *B*). If the rocks thus concentrated are abundant the resulting pile may help appreciably in stabilizing the foot of the slope, and if a retaining wall or drainage structure is to be built the rocks will be more readily available for such purpose.

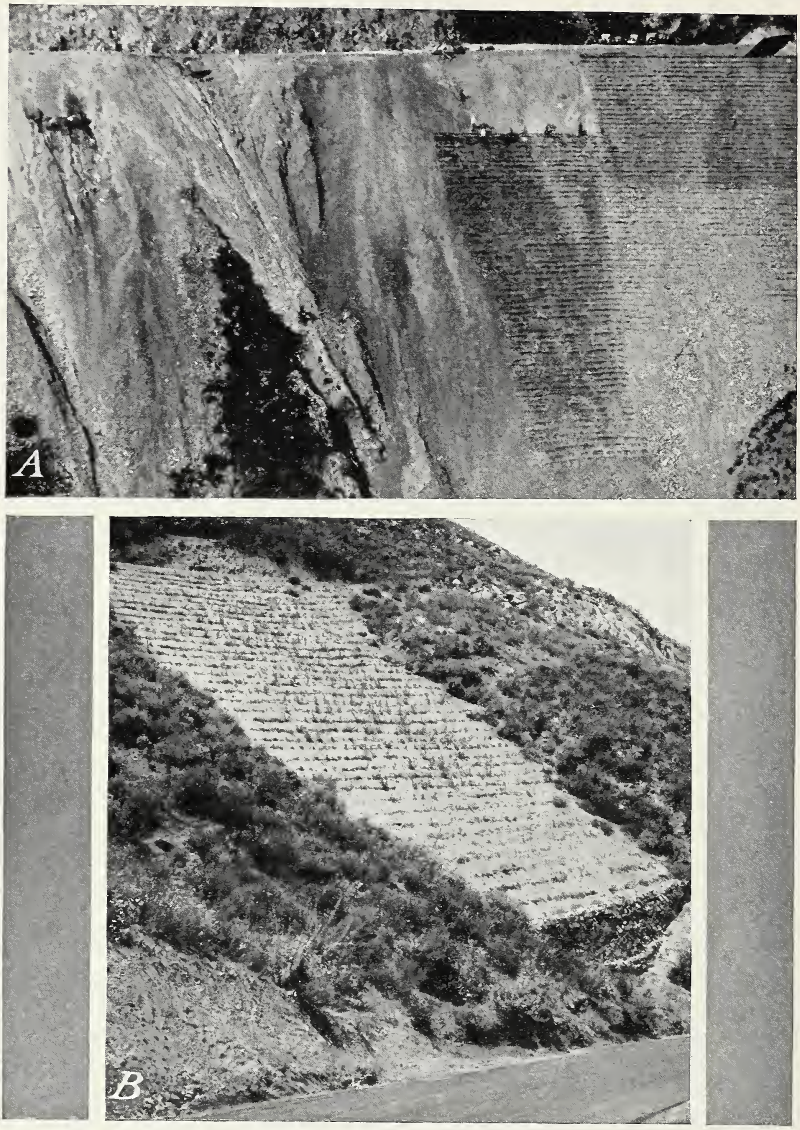
Retaining walls at the foot of road slopes are often necessary to prevent constant undercutting of the slopes by streams, or to keep the unconsolidated soil from creeping or sliding into lower roads or other improvements, such as camp grounds, cabin sites, or buildings (pl. 11, *B*). Such walls may be either dry-laid or cement rubble. Occasionally concrete walls may be used, since they are often cheaper, but in conspicuous situations rubble masonry of native rock is preferred for its more appropriate appearance in the mountains. Whereever these structures are required to restrain slopes close to buildings or public roads, or where they are to be carried to a height above 6 feet, it is imperative that they be designed by a competent engineer. For the smaller and less important structures a common rule of thumb is the following: Dry-laid walls should have a base equal to twice their height, rubble masonry walls should have a base equal to one-half their height. Both types should, of course, have their foundations excavated to solid ground, or to bedrock if this does not lie too deep.

MECHANICAL ANCHORAGE OF SLOPE SURFACE

The treatment employed for the protection and eventual concealment of new fill slopes on national-forest roads consists of contour wattling and planting. "Contour wattling" is an expression that



A, Example of extreme erosion in the case of a minor road or "truck trail" built as part of the fire control system. Poor location, inadequate drainage, and lack of slope fixation have resulted in almost complete washout of the sharp switch-back where the truck stands. Large volumes of eroded soil and rock have been deposited in the stream bed below. *B*, Rapidly eroding stretch of old road, after construction of new road on an easier gradient. Material eroded has swept down over the new road and also filled in a creek and small lake in an attractive recreation area below. Such roads should be plowed and planted with trees.



A, General view of erosion control work. Crew, upper left, smoothing rough slope, working from top. Upper center, wattling crew working up slope with conveyor; to left, a smoothed slope ready for wattling; to left again, a huge gully formed by drainage from culvert (black spot) above, too rough for treatment. (San Gabriel Canyon Highway, Angeles National Forest.) *B*, Controlled slope on a switch-back road, supported by dry-rock toe-wall that serves both to stabilize the slope and to prevent any possible sliding into lower road. Note beginnings of vigorous willow sprouts from planted cuttings. (Ortega Highway, Cleveland National Forest.)

has been adopted as a convenient name for a process somewhat different from that suggested by the dictionary definition of wattling. In this circular, wattling does not signify the weaving of twigs and withes between upright stakes, as in the customary wattle, but rather the packing of lengths of brush into continuous thick "cables" partially buried across a slope at regular contour intervals and supported on the lower side by stakes (fig. 3). Stakes may be made of inert material, such as split lumber, or, in the proper seasons, of living wood of species which take root readily from such cuttings.

Contour wattling serves a number of related purposes.

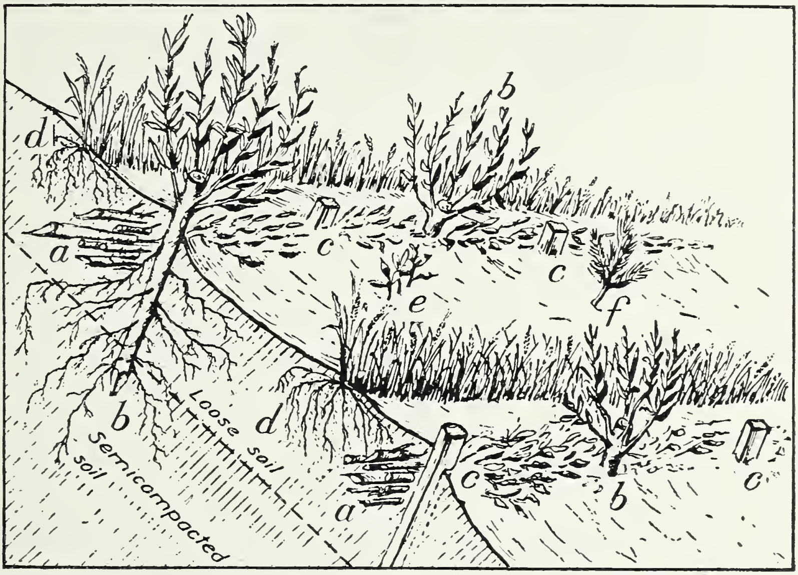


FIGURE 3.—Perspective of a section of treated slope: *a*, Stems of cut brush "wattles" imbedded in contour trench, with portion of leaves and twigs protruding above slope surface, giving slight terrace effect; *b*, stake of living willow or baccharis showing vigorous sprouts and good root system established—note that all stakes are set nearly at right angles to slope, not vertically; *c*, inert stake of lumber or locally cut forest material, long enough to stand firmly in the semicompacted soil; *d*, strip of cereal grain, 4 to 5 inches wide and 5 to 10 inches above the wattles, showing fibrous root systems—a temporary but rapid anchorage of the soil; *e*, cluster of shrub or herb seedlings growing from a seed spot of permanent-cover species; *f*, planted tree or shrub of permanent cover.

(1) It stabilizes the upper layer of soil to a depth of 6 to 10 inches against downhill surface movements such as are caused by the force of gravity aided by the wind, the trampling of deer, or even by such trivial disturbances as the rolling of pebbles or the scampering of squirrels. These dry slides carry with them any seeds which may be germinating in the surface soil, destroy small seedlings and injure larger plants, expose new layers of soil to similar destructive action, and start dry channels that lend themselves to more destructive action in the first rainfall. The wattle barriers when placed at intervals of 3 or 4 feet catch and intercept such dry slides while they are still minute and prevent their acceleration.

(2) Contour wattles intercept and form barriers against the downward gullying of the slope during heavy rains. The wattles tend to intercept and lead into the soil the surface water which otherwise

would cut ever-deepening channels down the fill; thus the soil particles are filtered out of the water and brought to rest. This function can be performed best if the brush wattles are nearly but not wholly buried in the contour trenches. Brush half buried will be undermined and the supporting stakes with it. Brush wholly buried will be overrun by the water and will not function until much sheet erosion has occurred and shoestring gullies have begun to cut down to the wattles. When the brush is carefully placed, leaving a substantial fringe of twigs and leaves protruding, the contour wattles will neither be undermined nor buried but will hold their own against the run-off, will prevent string gullying, and will cause the water to percolate into the slope soil for the use of vegetation.

(3) Another function of contour wattling is the prevention of slides. As earth is dumped upon the fill during construction, the first layers become more and more compacted by the impact and weight of the succeeding layers. This tamping effect continues in greater or less degree, depending largely on the character of the soil, up to within 15 to 30 inches of the surface. Here, especially on the upper half of the slope, the lack of tamping from above, aided by the drying action of the sun and wind, permits a thick layer of soil to remain relatively loose. Unless this surface layer is held in place by some mechanical means until the gradual effect of many wettings by gentle rains can cause a degree of cementation or the roots of growing vegetation can bind it to the firmer soil below, it may and in many instances does soak up such a load of moisture in heavy storms that the force of gravity severs its slight hold and causes portions of the layer at the top of the fill to slip down over the lower slope. In this process the great variations in degree of slip are attributable to the carrying proportions of clay, sand, broken rock, and organic matter in the fill material. Exhaustive research would be necessary to set up definite slide coefficients for material of different proportions, and when completed such rules would have little value because of the extreme variability of material even within a single slope. It is felt that such detailed research is hardly justified at the present time, since for practical purposes a working approximation of the sliding tendency of a fill can be made by any experienced engineer or road superintendent. Slides of this sort are largely prevented by the numerous stakes which, in connection with the contour wattling, are driven firmly into the compact lower soil and thus serve to anchor the loose top layer until plant roots make the bond permanent.

(4) By keeping the surface soil from moving, contour wattling performs a fourth function, that of making possible the start of vegetation on the fill. The wattles form miniature terraces, points of rest in which seeds of quick-growing grains can germinate to form the vanguard of the vegetational cover that is to break up the force of run-off and erosion and at the same time conceal the ugly scar made by the fill. Stakes of live willow and other sprouting species, wherever they can be employed, will develop into a bushy cover that will continue to hold the surface after the grain has died down, and carry on until the seeds of native shrubs, trees, and wild flowers sown between the contours have germinated and begun to take possession.

This artificial succession should culminate in a permanent cover of native shrubs, herbs, and trees growing upon a firm, compacted slope which bears no evidence of gullies or other serious soil movement. A road having its slope so treated will serve its purpose with a minimum of expense in upkeep, will have no record of damage to property below it, and will no longer deface a landscape that has definite recreational values.

STAKING, TRENCHING, AND WATTLING

Contour wattling is here described in detail, step by step, because unless the work is carefully and thoroughly done, its permanent effect may be largely or wholly lost. It is essentially a simple process, but it nevertheless requires the greatest care in operation and good judgment in its adaptation to local conditions.

Beginning at the bottom of the slope, the contour rows are alined with an Abney level and marked across the slope with enough guide stakes to make certain of the accurate completion of the rows by the workmen. The length of stakes used depends on the depth at which compact soil may be reached. The minimum length of the stakes should be 30 to 36 inches, of which all but some 3 inches is driven into the slope. Where the loose surface layer of the fill is 2 feet or more in depth, or the slope is steeper than 67 percent, longer stakes should be used, running up to 4 feet. The longer the stake, the more expensive and more difficult to procure; but if every fourth or fifth stake on such a slope is 40 to 48 inches, and the intervening stakes are 30 inches or more, this will go far toward preventing the surface slides and at the same time avoid the expense of a great quantity of the longer stakes.[6]

Contour rows should be spaced not more than 4 feet apart, and preferably about 3 feet. Distance between stakes may vary slightly, but should not exceed 15 to 18 inches. If the slope treatment is done in the late fall, winter, or early spring, at least one-fourth of the stakes used should be of willow, baccharis, elderberry, or other sprouting green material. The proportion will, of course, depend largely on the supply available. If the treatment is made in the dry season, inert stakes must be used, but with definite provision, wherever possible, for interplanting live stakes (cuttings of sprouting species) during the next dormant season.

Although any sprouting shrub or tree that is obtainable in the proper size is suitable for stakes, willow and baccharis are especially recommended. Willow is particularly desirable, both because of its ready and rapid growth and its universal distribution. The relative desirability of sprout material is further discussed in the following section, Sowing and Planting for Permanent Control.

As soon as a few rows of stakes at the bottom of the fill are set, the trenching and wattling crews get under way. The trencher, following the contour line already marked by the stakes and working with a hoe, lays open a trench just above the stakes approximately 6 to 10 inches deep and 8 inches wide. The dimensions of the trench are controlled by the size of brush bundles used. The trench should be so placed that the brush imbedded in it will rest directly against the stakes below (fig. 4, *C*). Both at this time and later in the operation, it is important that all unnecessary trampling on the slope be prohibited. Workers should be required to stand and walk always above the stakes in the trenches or, better still, on the embedded brush, and to take every precaution against disturbing the soil between the trenches. After the first two contours have been trenched, it may be desirable to halt trenching until the wattling has started. The trencher may thereafter work behind the wattling crew, walking along the newly laid brush while trenching the next contour above. He will thus have firmer footing and will cause little disturbance of the soil.

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[6] For stakes up to 36 inches in length 1- by 1-inch material is satisfactory; for longer stakes, up to 48 inches, 1- by 2-inch material is advised. In hard ground, 2- by 2-inch material may be necessary for the long stakes.

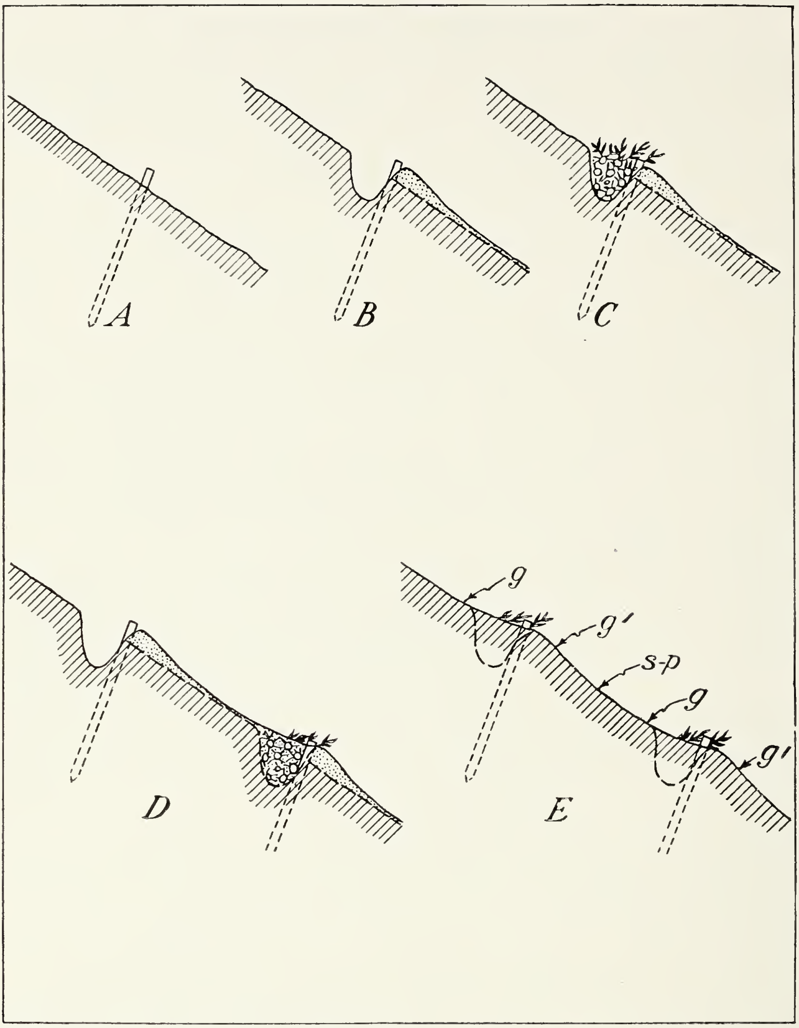

FIGURE 4.—Steps in contour wattling and planting: *A*, Stakes set in contour rows. *B*, Trench cut just above the stakes. *C*, Brush wattles packed into trench resting against stakes. *D*, Lower contour completed, with brush wattling partly buried by soil from next trench above. *E*, Sowing and planting; cereal grains are sown at *g* (and at *g′* in extremely loose soil or where wattles are 4 feet or farther apart); native seeds or plants are set at *s–p*.

Material for the wattles may be any stiff, woody, leafy brush that can be obtained in reasonably straight lengths of 3 feet or more, the longer the better. The size of stems used is immaterial excepting that long, slender branches are to be preferred to those that are short and thick. In general, material with stems more than 1 inch in diameter may be regarded as unnecessarily large. Wide-spreading and extremely stiff brush, difficult to compress, such as old oak or manzanita, is to be avoided.[7] The tops trimmed in making live stakes can always be used to advantage.

The selection of material for wattles will be simplified if it is kept in mind that the stems serve to give strength, to bridge the gaps between stakes, while the leaves do most of the soil holding, plug the spaces between stems and prevent trickling water from carrying soil down the slope. Therefore, if the only wattle material available is scant in foliage, such as chamiso, sage, mountain-mahogany, or dry willow and baccharis, it will be necessary to add some substitute material such as hay or forest litter. If grain or hay is used an added advantage will be realized from the seed which will sprout in the wattle rows.

The actual wattling should immediately follow the trenching, progressing from the base to the top of the fill. Although this is not a complicated proceeding, the success of the whole operation depends on a careful and consistent following of instructions by the crew. The brush is packed into the trench generally by two men who begin at one side of the fill and work across the slope, usually from left to right. One carries the material and hands it as needed to the packer; the other places and packs the brush. The packer, who moves along and stands on the previously constructed contour wattle below, should place all brush with the butts in the same direction and roughly spliced into the tops of the preceding clump, so that there will be a continuous overlapping of butts and tops. If the sections of brush are merely placed end to end without overlapping, the wattle will very likely give way at such points during heavy rains. It should be emphasized, however, that any attempt to weave the brush into any sort of braided structure is a needless refinement and expense. All that is wanted is a brush " cable " strong enough, with the reinforcement of the trench, to bridge the space between the stakes and withstand the tendency of the surface soil to creep downhill.

In placing the wattle brush, the packer should firm it into the trench as snugly as he can, using a little soil, if necessary, to hold the brush in place. On dry slopes he can allow for the soil pulled down by the trencher from the next contour above to pack in around the brush, as well as for the creep caused by the necessary trampling of the workmen as they walk back and forth over the contour. Dry soil thus dislodged will be sufficient to imbed the new wattles firmly, without covering them completely. On damp or wet slopes it will be necessary for the trencher to pull down soil from the slope just above the trench in order to approximate the effect of creep under dryer conditions.

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[7] For California, good species are California laurel, laurel-leaf sumac, and young sprouts of scrub oak and other chaparral species which spring from stumps of cut or burned plants. Willow and baccharis are good but must be used more generously because of their scant and papery foliage.

The carrier, watching closely the packer's work and supplying brush to the packer in convenient amounts and in a position from which the packer can fit it quickly and easily into place, follows at the left, standing on the packed brush just placed by the packer. In following the packer, he treads the brush firmly but gently into place, thus supplementing the other's work.[8]

A summary of the trenching and wattling operations may indicate more clearly how the two tasks are interrelated and supplement each other. Assume the lowest contour wattle completed and the trench of contour 2, above, already laid open. Carrier and packer start from the left side of the fill, the packer standing, for example, on the first completed contour as he begins packing brush into contour 2. The carrier follows him, standing on the brush just placed in contour 2 and throwing down the bundles of brush as needed into the trench ahead of him. Some distance behind, also standing on contour 2, is the trencher, digging out with his hoe the trench on contour 3 and, as may be needed when the soil is firm or moist, loosening earth just above contour 2 and pulling it over onto the brush. The result of pursuing the work in this manner is not only that the three tasks can be carried forward freely without interference, but also that each packed trench is subjected to at least six immediate tramplings, which include the firming in of a considerable portion of the earth from the trench or slope above. On large fills, by proper arrangement of the work and by rapid delivery of the brush from above, two or more wattle crews may be able to work the same fill simultaneously.[9]

A completed contour wattle should resemble a slight terrace, from the lower edge of which protrudes a windrow of twigs and leaves 3 to 4 inches long (pl. 12, *A*). As has been explained, this unburied portion of the brush is the safety factor. On a properly constructed contour the brush is neither so exposed as to encourage undercutting by the run-off of the first storm, nor so completely buried as to be overrun by water and silt. Construction of good contour wattles is by no means a difficult or delicate feat, but if it is not correctly done much, if not all, of the benefit desired therefrom will be lost.

Cut brush is delivered to the wattling crew in tied bundles by means of a simple high-line conveyor system such as that illustrated in plate 12, *B*. If several wattling crews are used on a large fill, it is probable that an extra deliveryman will be required to unhook the bundles and deliver them to the several carriers. One or two men will also be needed at the top of the slope to load and manipulate the conveyor, the number depending on whether or not the brush is delivered from the field in tied bundles. These are average needs. It is appreciated that each project will have its own peculiarities and that the disposition of manpower will have to be modified accordingly.

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[8] The details of crew organization for a big wattling job are given in the appendix together with a list of tools and equipment needed.

[9] The method sometimes employed of dividing a fill into equal left and right sections, with a separate crew for each half and the conveyor up the middle, is not recommended. Where more than one crew is employed, there is a distinct advantage in averaging their work by having all crews work clear across the slope, so that no one vertical or horizontal segment will develop weaknesses due to slipshod work on the part of any one crew.

On very short fills, or on slope gradients of 50 percent or less, hay or straw may be substituted for brush in wattling, with or without stakes, depending on the need for anchorage of the surface layer. In placing the straw the same care should be taken as with brush to leave a substantial fringe projecting from the partially covered trench.

In the effort to find a cheap and rapid treatment, the simple strewing of a slope thickly with hay, pine needles, or other forest litter, without wattling, has been tried; but the results, although good in some instances, do not warrant recommendation of this method except under the most favorable conditions. When this litter-blanket method is used, the cereal grains are sown in contour strips, as with the wattle method, but the strips should be placed closer together, about 24 to 30 inches, and the sowing of both grain and permanent-cover seeds should be done before the hay or litter is spread. Nursery-grown shrubs and trees can, of course, be planted through the litter at any favorable time. Control by this method will be greatly strengthened by staking the slope with live cuttings of willow or baccharis, as generously as funds will allow.

SOWING AND PLANTING FOR PERMANENT CONTROL

Contour wattling, notwithstanding its immediate effectiveness in protecting fill slopes against erosion, is after all merely a mechanical control which can remain effective only until the brush wattles begin to decay. For permanent control one must look to nature's own protection, a cover of living, self-perpetuating vegetation. As soon as soil movement on a slope has been arrested by wattling, an invasion of the slope by vegetation from the surrounding hillsides begins. This process, however, is slow and haphazard, and long before a complete cover could be established in that manner the disintegration of the slope by erosion between the scattered pioneer plants would be under way.

What is required, therefore, is an immediate cover of vegetation artificially introduced. This should be of three broad types, as indicated in figure 3.

(1) Temporary plants. Quick-growing cover plants with fibrous roots to protect the loose surface layer of soil (upper 12 inches) against gullying and excessive creep.

(2) Semipermanent plants. Deeper rooted plants necessarily somewhat slower of growth but more effective in anchoring the surface layer to the more compact deeper soil, so tending to prevent slumping when this layer is saturated by rainfall.

(3) Permanent plants. Native shrubs and trees that, although they may require several seasons for establishment, will finally complete the work of holding the hillside, and will ultimately develop a cover similar to that of the adjoining slopes.

TEMPORARY VEGETATION

The first class of plants should have the following qualities: Its seed should be abundant and cheap, and when field-sown, should germinate readily with the early fall rains and make quick growth before the heavy winter rains; it should have dense fibrous roots that will bind the soil quickly and firmly; it should be able to endure frost during its early growth without serious injury. In California, the plants that have thus far met these conditions best are the winter varieties of cereal grains, namely wheat, oats, barley, and rye. Through long selection these plants have been developed to a point where they surpass most other grasses in their speed and vigor of growth, strong fibrous root systems, and durable stubble. This lasting quality of roots and stubble is a valuable compensation for the short life of these annuals, since they remain effective in soil protection for several years after the plants have died. In other regions, studies will be necessary to determine which of the various grasses and herbaceous plants, native or adapted to the locality, will be best suited to local conditions.

The method of sowing as used in California is as follows: Beginning after the first fall rains, and after completion of the wattles, the cereal grains should be sown in 5-inch contour strips approximately 1 inch deep across the slopes, parallel to and a few inches above the imbedded wattles. Where the contour wattles are spaced more than 3 feet apart, a second strip of grain should be sown an equal distance below each contour, to prevent gullying from percolated water. The grain should be sown at the approximate rate of one seed to each square inch of surface. For wheat this would amount to about 5 ounces per 100 lineal feet of strip. Barley, oats, and rye, being heavier and containing fewer seeds per pound than wheat, should be sown at the rate of about 6½ ounces per 100 feet of 5-inch strip. These rates are not precise, but are a fair average for the varying sizes and weights of grains of different strains in different years and localities. Grain of known inferior quality should be sown more heavily. If too much grain is sown, however, the resulting crop, being rapid and aggressive in growth, will be so dense that it may injure other sown or planted vegetation by robbing it of moisture[10] (pl. 13, *A* and *B*).

Various pasture grasses, clovers, and other annuals, as well as many native species of herbs and grasses, have been tried; but for this pioneer task they have proved inferior to the grains in every respect. They cannot be depended upon to take and hold that first quick grip of the soil which is so essential. Mustard may be used where it is not objectionable locally, but its root system is much less fibrous and its single-stem habit less useful than those of the cereals. Its prime qualities are its ability to germinate in the autumn and to develop quickly a broad rosette of basal leaves which protects the soil from disturbance by driving rains, its resistance to frost, its ability to grow when sown broadcast, its prolific seed production and natural reproduction in the field, and its abundant seed readily available from commercial sources. Chief objections to the wide-spread use of mustard are the persistence which makes it difficult for desirable native vegetation to repossess ground on which the mustard is once firmly established, and the monotonous aspect of continuous roadside areas covered with a single plant to the exclusion of all others.

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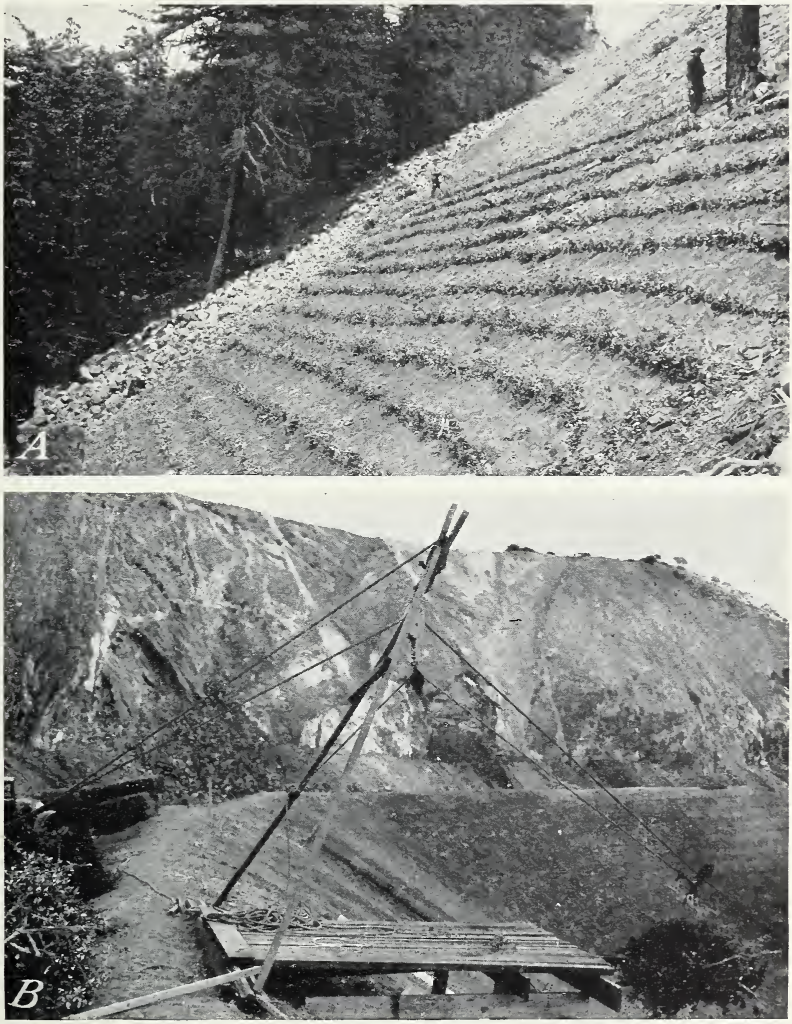
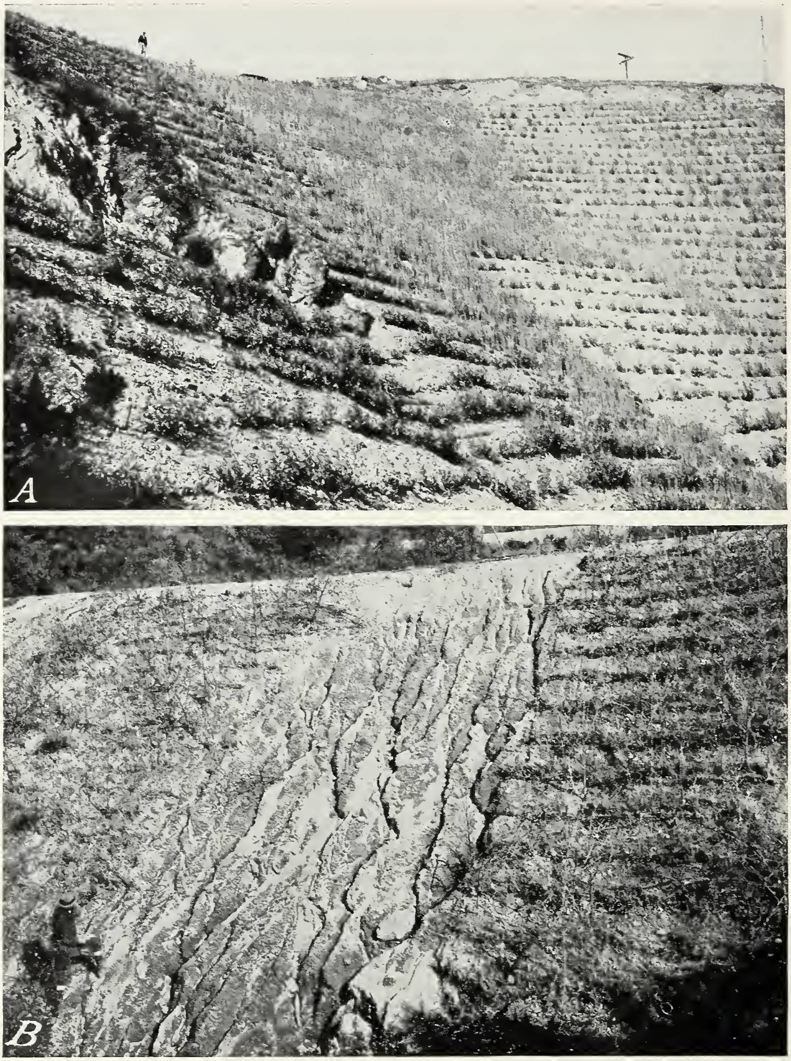
[10] In experimental treatments on Grizzly Peak Boulevard above Berkeley, Calif., dense sowings of wheat overtopped and killed red willows which had begun to sprout vigorously from planted cuttings at the same time that the wheat germinated. Where the wheat was less dense both wheat and willows thrived.



A, A 77-percent slope controlled by contour wattling, with wattles well buried and stakes set deeply; only a slight terracing effect has been produced. Cereal grain is being sown on the sloping benches above the wattles. By avoidance of high terracing the soil is kept close to the normal angle of repose. (Mill Creek Road, San Bernardino National Forest.) *B*, Conveyor platform and tackle rigged for delivering material to wattling crews, with bundle of brush suspended from trolley ready for descent. The scissors give maximum support and slope clearance to main cable if set at right angles to slope as shown. Shoulder berm of road in this picture is properly rounded to aid in preventing slump and improve appearance of road.



RESULTS ON EROSION-CONTROL EXPERIMENTAL PLOTS.

A, A controlled slope 3 months after completion. At left, willow sprouts are growing from stakes planted when dormant. In upper center, wheat has been sown so densely that many of the willows died or were stunted for lack of water. Wheat on upper right is of average good density. *B*, Three 20-foot erosion-control plots. That in the middle, untreated, lost 750 cubic feet of soil (more than 1,000 cubic yards per slope acre) and had to be refilled to save the road. Plot at left, sown to grain and sunflowers in contours, lost about 50 cubic feet. Right-hand plot, wattled and sown, lost only 15 cubic feet. Erosion rates on treated plots are negligible.

SEMIPERMANENT VEGETATION

To hold the ground after the short-lived cereals have died down, and before the permanent cover can become established, there is needed a type of vegetation which will thrive during the required period but will ultimately yield to the species desired for permanent cover.

Partly filling this requirement, the common sunflower (*Helianthus annuus*) as well as shrubby members of the composite family, such as desert ragwort (*Senecio douglasii*) and various species of *Chrysothamnus*, *Aplopappus* (section *Ericameria*), and *Encelia*, will occupy the ground for 2 or more years and occasionally persist in the final cover. All of these can be started by sowing the seed broadcast over the slopes after contour wattling has been completed.

Of more robust stature and longer life in this category are several shrubs and trees, such as willow, baccharis,[11] and elderberry, which grow well from cuttings and establish strong, deep-rooted plants in a season or two (pls. 14 and 15). Contrary to common opinion, the willow and baccharis, although occurring normally along stream sides and canyon washes, will nevertheless grow vigorously from cuttings on comparatively dry road slopes far removed from streams or other free water sources. Explanation of this paradoxical behavior lies in the absence of competing vegetation and in the deep planting of the cuttings, which together insure to the new roots exclusive use of all moisture available in the soil below the dry surface layer. The planting must be done, of course, during the period when the parent vegetation is dormant, i. e., between autumn and early spring. The planting of cuttings after the start of spring growth or during the summer is not recommended.

Willows.—This genus is so widely distributed that in every locality one or more species will be found suitable for use in this work. All species thus far tried have proven successful, and it is believed safe to recommend the use of whatever local species are most abundant and most conveniently situated. The species most commonly used in California have been the arroyo willow (*Salix lasiolepis*), red willow (*S. laevigata*) and Hind willow (*S. hindsiana*). At high elevations the Sierra meadow or Lemmon willow (*S. lemmonii*), a shrubby species, will probably give best results.

Baccharis.—One species of this genus, variously known as mulefat, water moat or motie (*Baccharis viminea*), has proved in California to be admirable material for road slope fixation. Sprouts from planted cuttings make prodigious growth in one season (pl. 15, *B*), as many as three sprouts from 7 to 10 feet high from a single cutting being not unusual. This is the more remarkable since the largest cuttings available from mature shrubs seldom exceed a diameter of 1½ inches, while the great majority are 1 inch or less in diameter. Full-grown shrubs present a somewhat ragged appearance with many slender upright stems, 10 to 50 or more in number, 6 to 10 feet high and one-half to 1½ inches in diameter. The lanceolate leaves cause this species often to be mistaken for willow, although it actually belongs to the composite or dandelion family.

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[11] Owing to the inconsistency or lack of common names for this plant in different localities of its range, the generic name *Baccharis* is here used without capitalization as the common name for purposes of simplicity and precision.

The species is abundant, occasionally forming dense thickets, in the gravel washes of streams throughout southern California, and it extends north to Sacramento Valley and Lake County. Where the natural supply is limited, it can be easily multiplied within a year by lining out cuttings on any available idle land, spacing the rows 2 feet apart and the cuttings 1 foot apart in each row. Better growth will be obtained if the land is plowed.

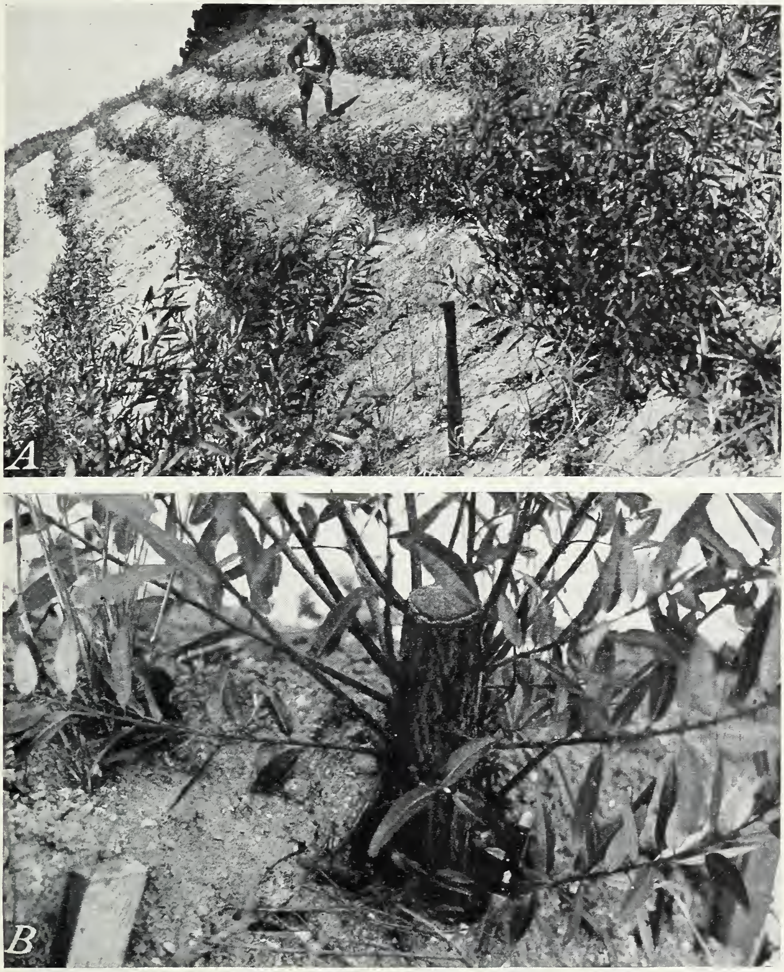
Another species, *B. pilularis*, one of the most abundant and widespread shrubs in the Coast Range, is well adapted to that locality. Although the old-wood cuttings sprout less vigorously than those of *B. viminea*, their growth is ample to make them useful in erosion control. This plant is locally called coyote brush and chaparral broom.

Still another species (*B. glutinosa*), commonly called water-wally, extends south and eastward from Owens Valley to Mexico and Texas. Somewhat more slender than *B. viminea*, it also grows similarly in the flood beds of streams. Although this species has not been used on roads in California, it is no doubt well adapted to such use within the range of its natural occurrence.

Elderberry.—All three species of elderberry occurring in California will sprout readily, but the one most commonly used thus far is the blue elderberry (*Sambucus glauca*). This species is classed with the semipermanent vegetation because it can be used for live-staking wattles in the same manner as willow and baccharis with almost equally good results. It is further desirable because, being well adapted to hillside conditions, it will thrive on the road slopes and will persist in the permanent cover. The beauty of its foliage and flowers lends interest to the summer roadside and its fruit is attractive to birds. Even though the blue elderberry is nowhere abundant enough to supply large quantities of cuttings, the fine qualities of the species will justify considerable effort to include at least a few plants on every treated slope. Research now in progress gives promise that other desirable native shrubs can be made to grow from cuttings under favorable field conditions.

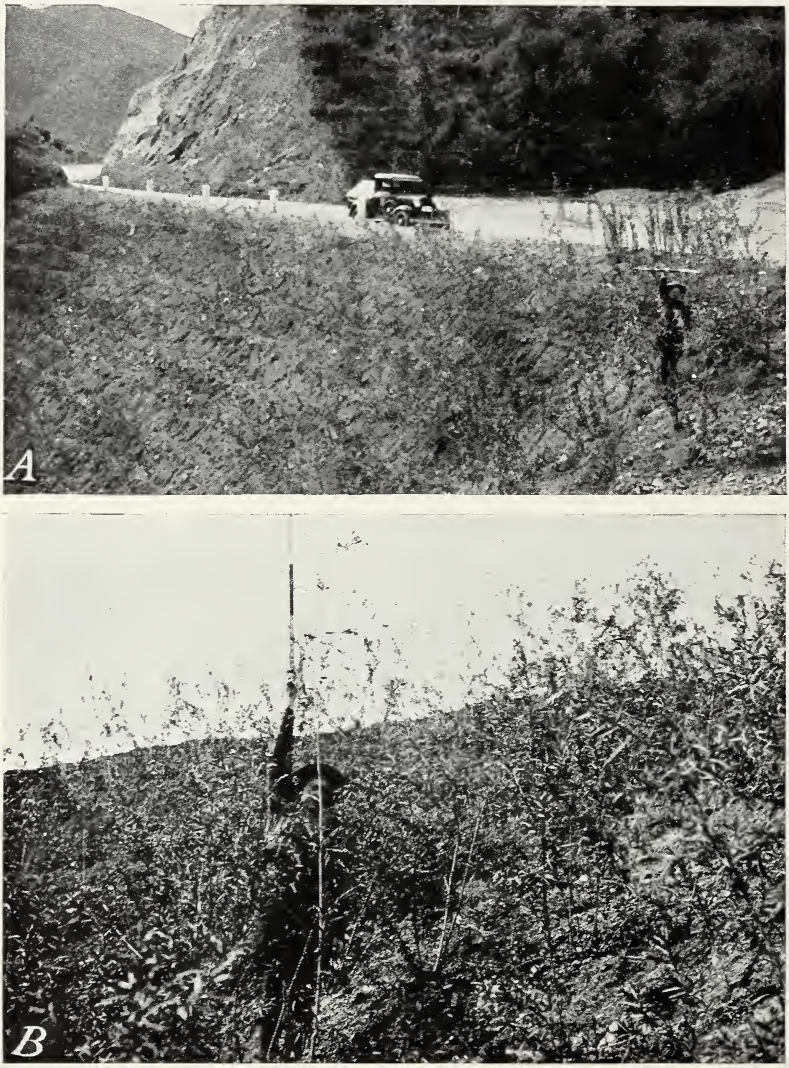
Preparation and planting of cuttings.—As previously indicated, these sprouting shrubs are most advantageously introduced on road slopes in the form of stout woody cuttings which serve as stakes to reinforce the contour wattles. Each treated slope acre requires from 7,000 to 17,000 stakes, depending on their spacing. If wattling is done during fall, winter, or early spring, when trees and shrubs are dormant, such live-wood stakes may be used exclusively, provided the supply is both abundant and conveniently situated so that the cost of their preparation will not be excessive. If wattling is done in summer, inert stakes of lumber should be used, and the cuttings may be introduced as follow-up plantings during the season of dormancy. In such cases some 4,500 cuttings per acre will be required to give a desirable plant spacing of about 3 feet each way. In preparing and planting the cuttings, whether of willow, baccharis, or elderberry, the following precautions may increase the chances for success:

(1) Cuttings of small diameter (up to 1½ inches) should be at least 18 inches long, and larger sizes can be any desired length beyond that, up to 4 or 5 feet.



WILLOW STAKE CUTTINGS SPROUT ON TREATED FILLS.

Excellent growth of common red willow from stake cuttings set to support contour wattles in early spring. *A*, Rows set 6 months previously. *B*, This stake has produced 23 vigorous sprouts in 6 months. (Grizzly Boulevard, Berkeley Hills, Calif.)



BACCHARIS WATTLES AND STAKES PROVIDE EXCELLENT COVER.

A, Use of baccharis in wattling results not only in holding soil but in a pleasing and marked contrast with bare untreated fills on similar roads. *B*, Baccharis sprouts at 11 months reached a maximum height of 10½ feet. Three or more sprouts from a single stake are a good average. (San Gabriel Highway, Angeles National Forest.)

(2) Cuttings up to 1½ inches diameter can be made effectively with two-handled pruning shears. The shears are operated by one man while another holds the willow stem and advances it the proper length for each cut. A machete or hatchet in the hands of an expert is a quicker method, though somewhat dangerous. Large diameters should be cut with axes, and substantial chopping blocks should be provided. All tools should be kept sharp. The butt ends of cuttings should be pointed to facilitate driving; this does not affect their rooting ability. Beveling the tops slightly reduces the chances of splitting, but this refinement can be dispensed with if care is used in driving.

(3) In planting cuttings, set them deep—the deeper the better, up to three-fourths of their length. Shallow planting results in too few roots below ground, too many leafy shoots above ground, and early death to the cutting because the scanty roots cannot supply water rapidly enough for the greater mass of foliage.

(4) Make sure the cuttings are planted right side up; i. e., with butt ends in the ground. It is not always easy to tell the top from the butt of a leafless cutting. A good rule is to have the butt ends of all stakes pointed immediately by the chopping crew at the time they are made; another way is to have the cuttings tied in bundles at the time they are first made, keeping the top ends together and marking that end of the bundle.

(5) In hard ground use an iron bar to prepare holes for the cuttings. This is to prevent stripping the bark in driving. Roots start from points in the inner bark; loosening the bark from the wood destroys this root-sprouting ability.

(6) Where stakes can safely be driven, as in soft moist earth, it is advisable to use a wooden maul or a broad-faced sledge hammer for driving in order to prevent splitting the stakes. Axes and small-faced sledges are especially damaging to stakes of large diameter. Although burred and split stakes will often take root and grow, the resulting shrubs will be subject to disease and to breakage by the wind.

In short, the objective in all handling of cuttings should be to avoid needless bruising and crushing of their soft growing tissues and to insure proper contact of the cuttings with the soil. The reward for such care will be a higher percentage of successful sets and faster, stronger growth of those which do take root (pl. 15).

PERMANENT VEGETATION

The first objective of the planting phase of road-slope fixation is to secure as quickly as possible a cover of vegetation which will protect the soil against erosion and hold the ground until displaced by a permanent cover. By " permanent " vegetation in this instance is meant an association of plants which are so well suited to the site that they will perpetuate themselves indefinitely and continue in full protection of the soil against erosion. The second objective is to hasten the establishment of this permanent cover by the sowing and planting of appropriate native species; and a third is to dispose the planted vegetation in such a manner that it will to a maximum degree efface the scars of construction and enhance the general attractiveness of the road.

A safe guide to the choice of plants for the permanent cover in any locality is the natural cover itself of that locality. By reproducing on a new road fill the types of plants found growing on adjacent undisturbed slopes one will achieve a cover not only harmonious with its surroundings but also well adapted to the local climate and soil. But, while this is perhaps the simplest and safest course to follow, other considerations may dictate various departures from it. It may be desirable, for example, (1) to vary a brush-covered hillside by judicious planting of large groups of trees for their mass effect, (2) to emphasize certain flower colors or extend them over a longer period by using more individuals of some desired species or by introducing species which do not occur locally, (3) to vary the monotonous appearance of a uniform slope by employing species having a foliage texture different from that of the local species, or simply (4) to add botanical interest by introducing numbers of species which do not happen to be abundant in the local cover.

From this partial statement of controlling principles it will be appreciated that the job of establishing appropriate permanent vegetation along new forest highways involves much more than merely the planting of seeds or miscellaneous nursery stock. It is a task which requires a wide knowledge of native vegetation, a balanced artistic imagination and a trained sense of practical values. It is, in short, a professional activity which may well be designated by the term "landscape forestry."

It is impossible to put into writing precise specifications for this kind of planting—each road and each fill is a problem in peculiar relation to its own environment, and its solution rests chiefly with the man in the field. Careful study of the elements which go to make up pleasing landscapes or natural plant compositions is the best training for rebuilding such compositions artificially. Indeed, the landscape forester is able, in a sense, to improve upon nature because he is able to control not only the placement of his materials but also their mass, by varying the proportions of different species in area and density.

Conditions favoring success.—In road-slope planting as here outlined several conditions favor the success of the permanent vegetation:

(1) The soil of fill slopes, although largely subsoil and therefore supposedly sterile, is usually found to produce excellent growth because of the thorough mixing and aeration to which it is subjected in the road-building process. In point of tilth a typical fill is comparable to a well-plowed field, although occasional exceptions are found in fills of coarse shale and gravel which hold very little water available to plants.

(2) Soil movement on the slope surface has been stopped by the contour wattles and the rows of growing cereals; hence, any subsequently sown or planted vegetation will be undisturbed during its germination and early growth.

(3) The semipermanent vegetation, chiefly willows and baccharis, acts as a nurse crop during the tender early growth of the permanent vegetation by supplying partial shade, and, as the permanent vegetation increases in stature, the nurse plants will be gradually overtopped and crowded out.

Planting instructions.—The following general rules are recommended for the permanent planting procedure:

1. Use species known to thrive in the locality. If species of uncertain adaptability are to be tested, either intersperse them with known species or set aside a definite area for experimentation where their possible failure will not entail serious consequences.
2. Plan the arrangement of species on each slope with an eye to the future, imagining what the slope will look like in 5, 10, and 20 years.
3. Avoid planting trees or tall shrubs in places where in a few years they will block attractive views.
4. Arrange all types of plants informally in groups, masses, or irregular bands. Avoid uniform geometrical spacing. In particular, never plant trees on a mountain road in straight lines or with soldierlike, equidistant spacing along the road's edge.
5. In general, the arrangement of plants on road slopes should be according to their habit of growth and stature at maturity, somewhat as follows:

(*a*) Creepers, prostrate shrubs, and low flowering plants (up to 12 inches), along the road shoulders and on cut banks;

(*b*) Taller annuals, perennials, and the more attractive shrubs (up to 4 or 5 feet), in an irregular band along the upper 10 or 12 feet of fill slopes;

(*c*) Larger shrubs and those less attractive, lower down on the slope and elsewhere as needed for general filling out of the cover;

(*d*) Trees, where trees are appropriate, along the sides and bottoms of the slopes, the tallest being lowest on the fill.

This arrangement is schematically shown in the appendix. What with the spreading of some species, the failure of others, and the occasional invasion of some from adjacent slopes, areas so planted will gradually blend with the natural cover of their environment.

The necessity of planting for erosion control, as herein outlined, presents an excellent opportunity to attempt the naturalistic landscape planting of mountain roads without extravagant cost. Indeed, plans are now in preparation for the planting of several representative roads in various parts of California as a test of the possibilities in this direction. It is to be hoped that the day is not far off when for every new road to be built in our mountains definite plans for scenic preservation and restoration, through naturalistic planting, will be prepared in advance, just as we now prepare engineering plans for their construction.

MAINTENANCE

As with other features of a new road, constant inspection and maintenance of the erosion-control work is especially important during the first rainy season after completion. At this time the sown and planted vegetation is in the early stages of development and the contour wattles must carry the entire burden of control. By the second season the temporary cover of cereals, herbs, and sprouted cuttings will have secured a good grip on the soil and the danger of failure will be greatly reduced. Inasmuch as the planting of the permanent vegetation will be carried on by a small trained crew after the temporary control work is completed, it should be possible to combine with their activities, at minimum cost, the regular and careful inspection of this work and such repair and general maintenance as is required.

ENGINEERING FEATURES

REPAIR OF BREAK-DOWNS

Intelligent maintenance starts with the knowledge of what to look for. Break-downs in road erosion-control work are of two general types: (1) Most common are gullies and side-cutting resulting from spillovers of road surface water at points where sufficient drainage has not been provided or where structures have become stopped; (2), failure of the slope treatment itself, usually in the form of sloughing or slump.

GULLIES

Since the slope treatment is designed to control only the natural rainfall on the slopes and not the concentrated drainage water, it is advisable to patrol the road during, rather than after, heavy rains to prevent trouble from drainage failures. Gullies which occur on wattled slopes in spite of all precautions, or for lack of them, should be repaired as soon as possible to prevent their enlargement. When the bottoms of such gullies are hard and smooth, as is often the case, they should be transversely scarified or trenched before being filled. The new fill should be compacted, if possible, by trampling and then should be heavily staked and rewattled. Stakes should be long enough to reach well into the compact bottom. If the gully is more than 3 feet deep, double staking may be necessary; that is, one set of stakes to be driven securely into the gully bottom before or during filling, and completely covered by the fill, and a second set, as part of the rewattling, to be driven in after the fill is completed. These two sets of stakes should overlap vertically by 12 inches or more, and the new wattles should either be firmly spliced with the old ones at both sides of the gully or should overlap them on the uphill side. The purpose of these measures is to improve the bond between the gully bottom and the new fill material and so prevent the new fill from sloughing out when it becomes saturated.

SLUMPS

Occasionally slumps will occur on controlled slopes during heavy rains. This sloughing, which generally carries with it wattles, stakes, and soil to a depth of a foot or more in patches or strips over the slope, results when a surface layer resting upon a compacted lower soil becomes saturated and the combined weight of soil and water causes a slip between the two layers. This is most likely to occur on slopes containing a large percentage of clay. Repair should be executed in much the same manner as described for gully repair, with the exception that greater care should be taken to establish the bond between the slump-exposed surface and the new fill. Trenches should be deeper or closer together and stakes larger and longer. If a shallow slump occurs well down on a large slope, so that fill material cannot be dumped into the gap without ruining a wattled area above, it may be possible to make repair without filling, by simply staking and wattling the exposed soil as if it were a new slope surface. In that case the edges of the slump should be rounded down, the wattles should be overlapped or interlocked with special care, and both wattles and stakes should be somewhat heavier than usual. It would be wise also to drive some extra long stakes in the slope immediately above the slump as a precaution against further sloughing.

CULVERT OUTFALLS

On some roads the repair or erosion-proofing of culvert outfalls, properly the duty of the road-maintenance organization, may have to be done by the erosion-control crew in order to halt or prevent disastrous undercutting of the slope. In no type of trouble is timely attention more important. It is not sufficient to guess at such a condition by casual inspection from the road. The downhill position of culvert outlets makes them hard to see, and therefore special pains must be taken to climb down the slope and inspect them at close range.

MAINTENANCE OF VEGETATION

Replacement of dead trees or other plants, where these have died for whatever reason, will be necessary only in critical situations or where the dead area is large enough to constitute danger of erosion through lack of protection. In most cases the growth of planted vegetation will not be so dense as to acquire cutting back, thinning, or trimming, but some of this may be necessary to keep ditches and other drainage structures clear, to maintain visibility in the roadway, or to keep open some attractive view from the road.

Since, on most projects, it will be possible to combine the permanent planting with the maintenance work, the crew handling these two jobs will be well qualified to undertake the replacement of vegetation. Further, such continuation planting, although primarily for the major purpose of erosion control, can with a little imagination become beautification planting as well. It comprises simply the sowing or planting of the most attractive and appropriate native species, whether trees, shrubs, or wild flowers, in well-chosen spots on cuts or fills where they will enhance the general attractiveness of the road. For all such planting it is perhaps needless to reiterate the admonition that native species are usually most appropriate on mountain roads, and that such species should be employed in preference to non-native species wherever possible. Desirable species for such planting are listed in appendix E.

APPENDIX

A.—EXAMPLES OF ROAD EROSION IN CALIFORNIA—DAMAGE CAUSED AND QUANTITIES OF SOIL MOVED

EXPERIMENTAL PLOTS

An experiment, started in 1930, on the Waterman Canyon road, San Bernardino National Forest, revealed loss of soil by erosion from several plots one-fortieth of an acre in size on a new fill, as follows, during the first winter after installation:

	Cubic feet
Plot A, slope sowed with cereals in contour strips	40
Plot B, slope untreated	400
Plot C, slope wattled in contours and sowed with cereals and sunflower	15

By the end of the second winter the untreated plot B had lost a total of approximately 750 cubic feet, i. e., 350 cubic feet during the second winter, or three-fourths the first winter's loss. Erosion on this plot had begun to encroach on the road shoulder to such an extent that the gullied slope had to be filled.

Plot A had lost a total of approximately 60 cubic feet, i. e., 20 cubic feet during the second winter, which was only half the first winter's loss.

Plot C suffered no perceptible loss of soil during the second winter. It appeared firmly stabilized and gave every appearance of remaining so with continued invasion of native vegetation.

RIM-OF-THE-WORLD DRIVE

The Waterman Canyon section of this highway has the distinction of revealing one of the most beautiful and extensive scenic panoramas, and yet of having caused by its construction some of the most spectacular landscape disfigurement and, by erosion of its fill slopes, some of the worst erosion-debris damage in California. Huge fills on high steep mountain sides were washed down the slopes in enormous quantities by intense rains, heavily charging the streams below with debris. This action was similar in every respect to a major flood from a burned area. No measurements were made of the volume of material eroded, but some idea of its magnitude can be gathered from the damage caused by the mud and boulder flows which resulted, as follows:

(1) Groves of alder trees in canyon bottom were broken off or torn out by the roots and deposited 1 or 2 miles down the canyon as macerated logs.

(2) Boulders weighing up to 2 tons were plucked from the creek sides and rolled down the canyon as by a major flood.

(3) A small bridge was wrecked and carried away several different times.

(4) Deposits of mud and boulders, left stranded in the receding stages of flow, were packed into pools and piled deep along formerly attractive stretches of stream bed.

(5) A 30-horsepower caterpillar tractor was carried downstream more than a mile and battered by boulders into a mass of twisted scrap iron.

(6) A series of debris dams built in the lower canyon to trap the debris were filled with detritus almost overnight, and were refilled promptly each time they were emptied, for 2 years thereafter.

(7) At the canyon mouth, mud and boulders were deposited in a large system of channels and ponds constituting the water-conservancy system of the municipal water department of the city of San Bernardino. Each time a flood occurred, the city was compelled, at considerable cost, to clear this material from the channels, ponds, and gates.

BELL CANYON ROAD

A fill of approximately 2.5 acres on a short stretch of road crossing the head of No. 1 Bell Canyon, San Dimas Experimental Forest, lost sufficient soil, in a storm which brought 11 inches of rainfall in 60 hours, to deposit 6,000 cubic feet of debris in a reservoir one-half mile below the road. An unmeasured additional quantity was left stranded along the stream channel.

Smaller quantities were deposited during subsequent lighter storms, and in the second winter a storm of 6.4 inches brought down 3,780 cubic feet from the same small road. The slopes had been treated in the interim, but the constant trampling by a large band of deer had so disturbed the work that its effectiveness was greatly reduced. A large part of this second deposit, however, had apparently come from movement of material previously left in the channel, much of which still remains to be transported during future heavy storms.

DALTON RESERVOIR

The Dalton Reservoir, located near the mouth of Big Dalton Canyon, has a drainage area of 4.3 square miles. A 12-foot standard road, constructed in 1932, cuts through a portion of the east half of this drainage for a distance of 2 miles.

Beginning on October 14, 1934, a 3-day storm occurred, which produced a total of 6.64 inches of rainfall. Maximum recorded intensities were 1.17 inches per hour for one 30-minute period and 1.0 inch per hour for a 1-hour period.

This single storm, not an unusual one for this section, brought down 125,000 cubic feet (4,600 cubic yards) of debris into Big Dalton Reservoir. This debris can be traced wholly to erosion of the 2-mile stretch of road mentioned above. Deposition figures were obtained from accurate surveys of the reservoir made prior and subsequent to the storm.

GLENDORA MOUNTAIN ROAD

An erosion delta has been deposited in Pine Canyon Reservoir, San Gabriel River, from less than 1 mile of the Glendora Mountain road cutting across the head of Garcia Canyon. This deposit amounts to approximately 80,000 cubic yards and is chargeable entirely to the road. Other deposits from the road now in Garcia Canyon are gradually being moved into the reservoir during heavy rains.

DEVIL'S GATE RESERVOIR

The Devil's Gate Reservoir controls 30 square miles of the Arroyo Seco drainage and has a storage capacity to spillway crest of 4,608 acre-feet. In 14 years (1920–September 1934), 511 acre-feet of silt were deposited in the reservoir, reducing the capacity by 11 percent (silt figures were determined by instrument surveys of the reservoir in 1916 and September 1934). Since no fires of any extent occurred on the watershed during this 14-year period, the major disturbance was in the form of roads, principally the high-standard Angeles Crest Highway. This highway cuts through the Arroyo Seco drainage for a distance of 10 miles, and has been the chief source of erosion from which the deposits have been formed.

DAMAGE TO RECREATIONAL USES

A survey has been made by the California Forest and Range Experiment Station of the amount of damage to recreational uses from road erosion in the Arroyo Seco watershed above Devil's Gate Reservoir. The monetary losses listed below for the various items are very conservative, and actual values may be considerably higher. In addition, the intangible losses, such as damage to scenic values in once beautiful canyons and the loss in storage capacity of the Devil's Gate Reservoir mentioned in the paragraph above, were not estimated.

From Angeles Crest Highway: Damage to—	
Cabins	$4,200
Road (Arroyo Seco)	10,000
Road (Dark Canyon)	2,500
Camp ground R	1,000
Canyon bottoms (Dark Canyon)	(1)
From Angeles Crest Service Road: Damage to cabins	250

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[1] Complete ruin.

Camp ground R was covered by 7,000 cubic yards of material from the Angeles Crest Highway during one heavy storm of the 1934–35 season.

B.—ESTIMATED SPECIFICATIONS FOR LABOR, EQUIPMENT, AND MATERIALS

LABOR

The size and distribution of wattling crews are influenced by so many conditions of site, source of materials, availability of labor, and so on, that any definite estimate of labor needed on any particular job is impossible. The most that can be done is to indicate the distribution of a typical unit crew with the equipment required, etc., as a rough guide for such operations.

The minimum unit crew may be regarded as 15 men. If work is done in the rainy season, so that live cuttings can be used for stakes, the crew will be distributed somewhat as follows:

	Men
Cutting and preparing live stakes	5
Cutting and bundling brush	3
Truck-hauling brush and cuttings	1
Smoothing, staking, trenching, and wattling slope	6
Total	15

If the work is done in summer, and stakes are used, four men of the stake crew will be available for smoothing the slopes, a task that can to great advantage be handled independently and ahead of the staking and wattling. Distribution of the whole crew might then be as follows:

	Men
Cutting and bundling brush	4
Smoothing slopes	4
Laying out and staking contours	2
Trenching contours	1
Packing wattles in trench	2
Carrying brush, and general utility	1
Truck-hauling of brush	1
Total	15

On smaller projects where a smaller crew must perforce be used, a 10-man unit could probably be utilized to best advantage as follows:

	Men
Cutting and preparing brush	3
Cutting live stakes or smoothing slope	3
Staking, trenching, and wattling	3
Trucking	1
Total	10

On large fills with many acres of slope, crews up to 40 or 45 men may prove economical. If such a crew is regarded simply as a multiple of the 15-man unit crew, the above estimates may still serve as a rough guide to its distribution.

LABOR REQUIREMENT PER SLOPE ACRE

What such a crew can accomplish in terms of man-days per slope acre can only be broadly indicated here. Season of year, type of soil, percent of slope, materials available, and many other factors which vary with every job—some varying radically with every half mile of fill—make any attempt to reach a dependable average figure an impossibility. If any estimate be allowable, as the merest indication of possible performance, it is that a reasonably experienced crew of 15 men, including truck driver, may complete stake and brush cutting, trucking, preparation of slope, running staked contours, and wattling on 1 slope acre in 8 to 10 days. Where lumber stakes are bought, the operation time should be less. Inexperienced crews and difficult character of slope will greatly increase the time required. Eighty to a hundred man-days may be required for the preparation of a single acre of badly eroded slope. Accessibility of materials may release the labor of 3 or 4 men for a second wattling crew, thus greatly speeding up the whole job.

In all this indefiniteness as to time and labor required, one consideration stands out clearly as a guide to efficient performance. That is, that careful, conscientious work is of far more importance than anything else in erosion control on road fills. If the job is not intelligently planned and painstakingly carried out, with full consideration for local conditions and requirements, the entire time spent on the work may be lost. If 30 or 40 man-days more are necessary to insure the careful driving of stakes and proper laying of wattles, the added cost may be more than justified by the greater security of the whole project.

EQUIPMENT

The question of crew equipment is also one that admits of no categorical answer. The following list of equipment for a typical 15-man unit will, however, prove adequate under average circumstances:

1 Abney level, for locating contours.
6 pruning shears, two-handled, for trimming cuttings and brush, and for cutting brush.
2 brush hooks for cutting brush.
4 axes, double bit (with extra handles) for cutting live stakes.
4 axes, hand, small (with extra handles) for pointing stakes.
2 hoes, grading, for smoothing and trenching.
2 hoes, garden, for trenching and smoothing.
500 feet of ¾-inch rope, for conveyor main line.
500 feet of ¼-inch rope, for conveyor haul-back.
1 block and tackle.
1 pulley.
6 mattocks, for smoothing slopes.
4 crowbars, for loosening rock and preparing holes for live stakes.
2 mauls, made on the job from 6- by 8-inch live oak, for driving stakes.
3 shovels, long-handled, round-pointed, for smoothing slopes.
6 files.
2 carborundum stones.
15 canteens, 1-gallon size.
5 pounds of binder twine per week. Old baling wire, if obtainable, is preferable, as it may be used again and again.
Hammer, saw, and nails, for building platforms and conveyor set-up.
First-aid kit.

STAKES REQUIRED PER SLOPE ACRE

Stake requirements are given in table 1 on the basis of different desirable spacings, as may be dictated by conditions on the slope. For summer work, 100 percent of the stakes will be inert (lumber or dead material cut on the job). For fall, winter, or early spring work, 25 percent or more of live stakes (cuttings of willow, baccharis, etc.).

TABLE 1.—*Stake requirements*[1] *per slope acre for different spacings and different percentages of total used*

CONTOUR ROWS 30 INCHES APART

Stakes inert or live (percent)	Stakes 12 inches apart	Stakes 15 inches apart	Stakes 18 inches apart	Stakes inert or live (percent)	Stakes 12 inches apart	Stakes 15 inches apart	Stakes 18 inches apart
	Number	*Number*	*Number*		*Number*	*Number*	*Number*
100	17, 424	13, 939	11, 616	30	5, 227	4, 134	3, 485
75	13, 068	10, 469	8, 712	25	4, 356	3, 470	2, 904
50	8, 712	6, 970	5, 808				
CONTOUR ROWS 3 FEET APART							
100	14, 520	11, 616	9, 680	30	4, 356	3, 485	2, 904
75	10, 890	8, 712	7, 260	25	3, 630	2, 904	2, 420
50	7, 260	5, 808	4, 840				

[1] For recommended stake sizes, see p. 15.

TABLE 1.—*Stake requirements per slope acre for different spacings and different percentages of total used*—Continued

CONTOUR ROWS 3½ FEET APART

Stakes inert or live (percent)	Stakes 12 inches apart	Stakes 15 inches apart	Stakes 18 inches apart	Stakes inert or live (percent)	Stakes 12 inches apart	Stakes 15 inches apart	Stakes 18 inches apart
	Number	*Number*	*Number*		*Number*	*Number*	*Number*
100	12,446	9,957	8,297	30	3,733	2,987	2,489
75	9,334	7,467	6,223	25	3,112	2,490	2,074
50	6,223	4,978	4,149				

CONTOUR ROWS 4 FEET APART

100	10,890	8,712	7,260	30	3,268	2,614	2,190
75	8,168	6,534	5,445	25	2,722	2,178	1,815
50	5,445	4,356	3,630				

C.—OUTLINE OF PROCEDURE IN CONTOUR WATTLING

PRELIMINARY SURVEY OF PROJECT

MAP

A map of the entire project is very desirable. If a copy of the road-alinement map is not available, a simple sketch may be made, on a scale large enough to show all fills, cuts, drainage, structures, walls, etc. Fills need not be drawn to scale but should be designated by consecutive numbers or by the road station numbers.

INSPECTION OF DRAINAGE

Inspect thoroughly the drainage system on the entire project, giving attention to all the points previously discussed under the heading Drainage Improvement (p. 8). Note particularly the places where drainage is emptying directly out upon fill slopes and causing erosion. Make plans for the corrective measures required to lead all water to natural channels, carrying it to the bases of slopes in culvert pipe or half culvert wherever necessary to prevent gully cutting. Examine all culvert outfalls and note what reinforcement may be needed, whether structural or planting.

SURVEY OF FILLS

Examine all fills and record the character of each fill separately. The dimensions, area, percentage of slope, nature of soil (as loose sliding sand, loam, clay loam, etc.), rock frequency and size, area of surface rock, and any other significant details should be carefully recorded on forms similar to form no. 1, shown on page 35.

Each fill should be numbered or marked with its station number. Each side slope of a through fill should be given its own separate number. Where more than one type of treatment is to be given a fill, the area of each type of treatment should be kept on a separate section of form no. 1 and designated by a special letter under the fill number, as 14–A, 14–B, etc. To determine the surface area of each fill, the foreman should either make a stadia survey or measure the area and determine the slope with an Abney level. In measuring such areas, do not "break chain" but measure *along the slope* and compute the surface area *on the slope*.

LOCATION OF MATERIALS TO BE USED

Before a working plan can be prepared, it will be necessary to do some scouting to locate suitable stands of brush or trees for wattle material and, if work is done in the wet season, for cuttings, or live stakes. If possible, these should be selected within easy transportation distance. They should never be taken where the cutting will be permanently unsightly.

Species suitable for wattles and live stakes are discussed in the section entitled "Staking, Trenching, and Wattling" (p. 15). Willow and baccharis are to be preferred for live stakes, and their trimmings can be used for wattle brush. Other good California species for wattles are California laurel, young scrub oak sprouts, laurel-leaf sumac, wedgeleaf ceanothus (*Ceanothus cuneatus*), and mountain olive (*C. crassifolius*). In estimating brush supplies do not count on clear cutting except on firebreaks or similar sites where this method is desirable. In all other cases about 30 percent of the cover should be left standing and all brush taken should be cut close to the ground.

If work is done in dry season, inert or dead stakes must be used. These can usually be purchased more cheaply than they can be cut, if funds are available. If man power rather than money can be used, stakes may be cut in the field from scrap lumber or from dead standing timber. Adequate supplies of such material should be arranged for before the work on the fills is begun. For recommended stake sizes see page 15. For number of stakes required per slope acre see table 1.

PREPARATION OF WORKING PLAN

From the information gathered a comprehensive working plan should be prepared for the entire project, grouping the fills requiring similar treatment, type of labor, supplies, equipment, etc. This plan should show the total quantities of all materials needed, by types, sizes, and means of supply (as buying or cutting of dead stakes). It should specify the size and number of unit crews to be employed and should contain an estimate of the total number of man-days required. Estimates for this type of work, because of its many variable elements, cannot be calculated as closely as for ordinary engineering construction. If the estimates are later found too low to permit completion of the project on the required standards, there should be no effort to stretch the remaining resources over the whole project by reducing the quality of treatment. It should be emphasized that staking and wattling are economical only when carefully and thoroughly done, while inadequate work will usually fail and be completely wasted. It would be preferable to leave some slopes untreated altogether than to cover all with hasty and slipshod work.

Estimate similarly the amount of motor-truck hauling in truck-hours, and the size of truck needed. This item can be estimated more accurately than wattling time, since it depends largely on the source of materials, which should have already been determined.

List all tools, tackle, and other equipment needed. The list of average equipment for a 15-man crew, given on page 31, will serve as a guide.

PROCEDURE ON THE JOB

Smoothing the slope and cutting brush and stakes (or hauling a sufficient supply of purchased stakes) are the first items for attention, since wattling cannot proceed until at least one slope is completely smoothed and an ample supply of wattling material is at hand. The whole crew can well be placed upon these two jobs until a satisfactory lead is obtained.

In smoothing slopes, work from the top downward and make sure that the rolling of dislodged rocks will cause no damage at the foot of the slope. A heavy brush barrier may serve to hold the rocks until enough have accumulated to form a rough toe wall at the foot of the slope before smoothing is completed. A rule of thumb for a dry rock wall is to make the thickness of the base equal to twice the height. Where cribbing or retaining walls above 6 feet in height are required, they should be designed and laid out by qualified engineers. (Refer to pp. 11–15.)

If weather conditions are at all uncertain, smoothing should never be more than one slope ahead of staking and wattling, since otherwise a certain amount of gullying is bound to occur, requiring that the slope be gone over again. When at least one slope is smoothed, start two men with Abney level, mauls, and stakes alining the contours, beginning at the bottom of the slope. After a row has been lined out across the fill with a few stakes by one man, both can then complete the staking for that row before proceeding to the next contour above. Space the rows preferably 3 feet apart, not more than 4 feet. Recommended space between stakes is 15 to 18 inches. Where two sizes of stakes are used (as 30-inch and 40- or 48-inch) the longer stakes need not be placed more frequently than every fourth or fifth stake, but they should be distributed from row to row so that they do not fall into a line above one another on the slope.

Rig up the conveyor system, as illustrated in plate 12, to convey materials from the road to the crews.

When two or more rows are staked, start the trenching and wattling crew, working them preferably in the manner described on pages 15–19. Trenches must be hoed out so that brush can rest directly against stakes they must not be so deep that brush wattles are completely covered.

Bury wattles in trench so that a fringe of twigs and foliage will project 3 or 4 inches when the contour is completed. The brush must be continuously staggered in the trench, i. e., tops overlapping butts, to form a continuous cable reinforcement for the soil. Avoid developing prominent terracelike structures which result from piling earth on excessively thick masses of brush. Workers doing the wattling should be carefully instructed in this work and should be frequently inspected. Merely throwing the brush into the trenches and raking soil over it is not satisfactory work.

Crews, in moving about their work, should be trained to walk in the trenches, or preferably on the buried wattles to pack them down. The soil between contours should not be disturbed any more than necessary.

SOWING AND PLANTING

When the major job of wattling is done during summer all sowing and planting, including the setting of cuttings, must be postponed until fall when it can be handled by a follow-up crew. The sowing of the cereal grains (wheat, rye, oats, or barley) and of other seeds which do not require soaking, may be started before the first fall rains but as close to them as it is possible to judge. Other sowing and planting should be done after the rainy season is well begun and the ground is thoroughly moistened.

On some forests a trained planting crew may be available for this important work. If not, then a group of 6 or 8 of the most experienced men on the wattling crew should be reserved for this purpose. While the sowing of the cereal grains and all seeds which can be broadcast, and the setting of willow cuttings, can be left to the direction of the crew foreman, the permanent planting should be carefully planned and supervised by the best qualified man available. This job also must be more carefully timed with favorable weather, and hence may have to be done intermittently. If such is the case extra care should be taken to avoid loss of planting stock by needless exposure during unfavorable periods.

For further detailed instructions on sowing and planting refer to the discussion beginning on page 19.

D.—FORMS FOR RECONNAISSANCE AND COST RECORDS

The following forms have been developed in the course of large-scale projects on California roads. Form no. 1, for convenience, accommodates descriptions of three fills on one sheet. As stated in the preceding section of the appendix, where slopes of a single fill call for differences in treatment, they should be designated and recorded separately by letter, as fill 17, slope A, etc. Modifications in treatment made as the control work progresses should be entered on form no. 1 as a matter of record.

Form no. 2 covers the labor record for a single fill, as this will usually prove the most convenient way to keep it. If truck-hours does not include driver's time, this should be noted. Type of labor requires such information as C. C. C., N. I. R. A., Regular, etc. Where two or more types of labor are used on the same fill, it may be desirable to keep separate record for each.

Form no. 3 covers any number of fills, since materials purchased will ordinarily be distributed over several sections of the whole job. In obtaining cost per fill it will be necessary to select items accordingly from column "Cost per fill."

Form no. 4, covering summary of costs, should record on a single sheet only the costs for identical or very similar methods. Fills treated by different methods should be grouped on separate sheets. A number of sheets may accordingly be required for a complete monthly record.

Road Erosion Control Form No. 1

RECONNAISSANCE

National forest__________________ Highway__________________ Date______

FILL NO.	Nature of soil:
SLOPE Width	Rock frequency and size:
Depth	Immediate control measures:
Area	
Percent	Follow-up measures:
FILL NO.	Nature of soil:
SLOPE Width	Rock frequency and size:
Depth	Immediate control measures:
Area	
Percent	Follow-up measures:
FILL NO.	Nature of soil:
SLOPE Width	Rock frequency and size:
Depth	Immediate control measures:
Area	
Percent	Follow-up measures:

Road Erosion Control Form No. 2

LABOR RECORD FOR FILL NO. ____

National Forest__________________________ Highway____________________
Type of labor____________________________ Working ______ hours per day
Record from__________ 19__, to__________ 19__. Foreman____________________

Date	Labor (man-days)							Truck-hours (with driver)
	Preparing slope	Cutting—		Staking, trenching, wattling	Seeding, planting	Miscellaneous [1]	Total	
		Brush	Stakes					

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[1] Includes drainage correction and retaining walls.

Road Erosion Control Form No. 3

MATERIALS PURCHASED

National Forest---------------------------- Highway----------------------------
Record from---------- 19--, to---------- 19--. Foreman--------------------

Quantity	Description	Used on fills nos.	Cost per fill	Total cost

Road Erosion Control Form No. 4

MONTHLY SUMMARY OF COSTS FOR MONTH OF----------, 19--

National Forest---------------------------- Highway--------------------

Fills nos.	Description of method

Item of cost	Man-days	Rate per day	Total cost
LABOR:			
Preparing slope			
Cutting brush			
Cutting stakes			
Staking, trenching, and wattling			
Seeding and planting			
Miscellaneous			
Total labor			
	Truck-hours	Rate per hour	
TRUCK, with driver			
MATERIALS, total cost for above fills			
SUPERVISION			
Total cost			
Surface treated ------ acres			
Cost per surface acre			
Acre cost excluding combing slope, drainage, walls, etc			

E.—PLANTING DISTRICTS AND PLANT LISTS

The purpose of this section is to suggest a list of trees, shrubs, and other plants suitable for planting for purposes of erosion control and scenic restoration along mountain roads in California, and to indicate sections of the State to which each species is adapted. Since native plants are most appropriate for such planting, only seven species not native to California have been included because of especially desirable qualities which they may possess.

A division of the California region into planting districts as shown below has been adapted from that devised by L. Glenn Hall, landscape engineer of the Forest Service in San Francisco. Each district and elevation belt constitutes a minor climatic province somewhat different from the others. In table 2 each species is marked with the numbers and letters of the districts and elevations in which that species can be expected to grow. It should be understood that all these designations are very broadly generalized. Nearly all species have a wide geographical range of adaptability, provided they are planted locally in sites favorable to their needs. For guidance in this placement of species the list includes a column headed "Native Habitat", describing briefly the conditions under which each species is most commonly found growing naturally. In another column is suggested the position on fill slopes to which the species is best suited, the symbols referring to the diagram which follows the plant list.

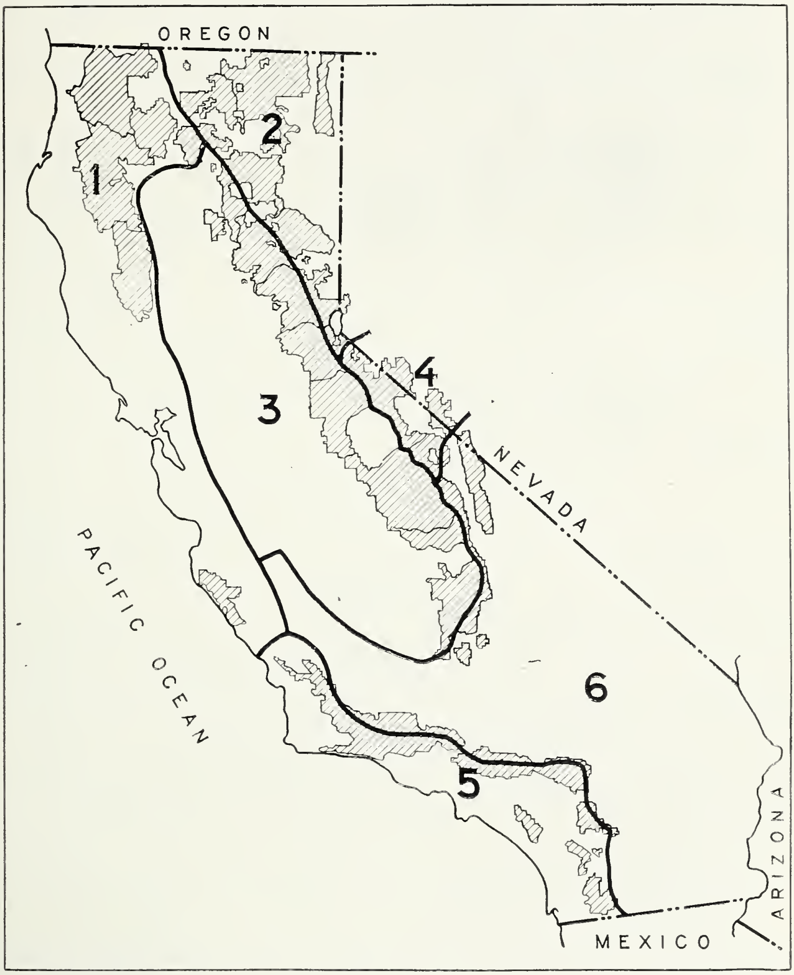

FIGURE 5.—Road planting districts in the California national forest region.

PLANTING DISTRICTS IN CALIFORNIA

1. North Coast Range (and Monterey coast): National forests: Klamath, Trinity, Mendocino, western portion of Shasta, and Monterey division of Santa Barbara:

	Elevation in feet
(*a*) Fog belt	100–1, 500
(*b*) Foothill chaparral belt	1, 500–2, 500
(*c*) High interior valley	2, 500–3, 500
(*d*) Ponderosa pine slopes	Above 3, 500

2. Northeastern California (Oregon line to Lake Tahoe): National forests: Modoc, and eastern portions of Shasta, Lassen, Plumas, Tahoe, and Eldorado:

	Elevation in feet
(*a*) Creek and river canyons	2, 500–3, 500
(*b*) Sagebrush valleys	3, 500–5, 500
(*c*) Ponderosa pine plateaus and slopes	4, 000–6, 000

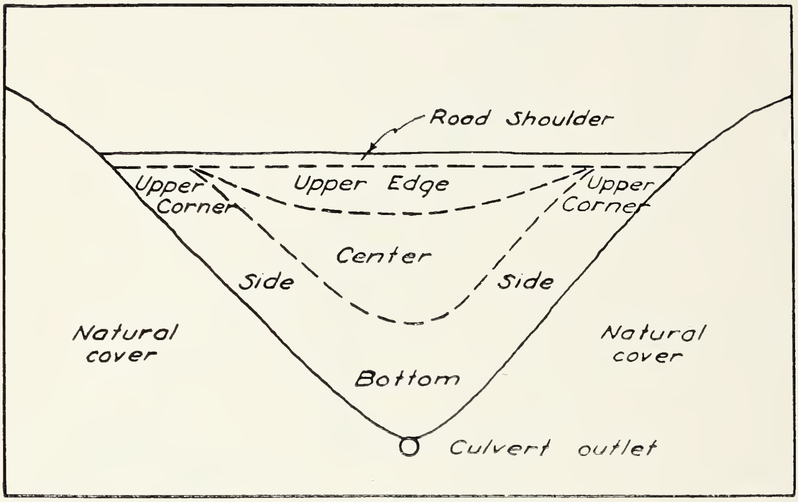

FIGURE 6.—Planting positions on a fill slope.

3. Sierra Nevada, western slope (south of Pit River): National forests: Stanislaus, Sierra, Sequoia, and western portions of Plumas:

	Elevation in feet
(*a*) Valley grassland	500–1, 000
(*b*) Foothill chaparral	1, 000–3, 000
(*c*) Ponderosa pine slopes	3, 000–5, 000
(*d*) Fir and lodgepole pine	5, 000–7, 000
(*e*) Timberline zone	7, 000–9, 000

4. Sierra Nevada, eastern slope: National forests: Mono and northern portion of Inyo:

	Elevation in feet
(*a*) Sagebrush valleys	3, 000–5, 000
(*b*) Jeffrey pine woodland	5, 000–6, 500
(*c*) Lodgepole pine timber	6, 500–9, 000

5. Southern California, coast: National forests: Coastal portions of Santa Barbara (except Monterey Division), Angeles, San Bernardino, and Cleveland:

	Elevation in feet
(*a*) Fog belt	100–1, 500
(*b*) Foothill chaparral (including pinon pine and semidesert areas)	1, 500–3, 000
(*c*) High interior valleys	3, 000–5, 000
(*d*) Yellow pine flats and slopes	3, 500–7, 500

6. Southern California, semiarid and desert interior:[12] National forests: Those portions of Inyo, Sequoia, Santa Barbara, Angeles, San Bernardino, and Cleveland bordering desert:

	Elevation in feet
(*a*) Dry valleys and canyons	500–1,000
(*b*) Dry valleys, mesas, and canyons	1,000–2,000
(*c*) Dry valleys, mesas, and canyons	2,000–3,000
(*d*) Dry valleys, mesas, and mountains	3,000–4,000

TABLE 2.—*Plant list for the California region*

Species	Size [1]	Native habitat	Planting district	Position on slope [2]	Remarks [3]
Conifers:					
Abies concolor, white fir	L	North slopes	4bc, 5d, 3d, 1d, 2c.	S, B	Nursery stock or sow seed in fall.
Abies grandis, lowland white fir.	L	Well-drained soil, fog belt.	1a		
Cupressus arizonica, Arizona cypress.	M	Dry east and west slopes.	Below 1,500 feet.		
Cupressus macnabiana, MacNab cypress.	M	do	1c, 2b, 3b		
Juniperus occidentalis, western juniper.	S	Hot, dry sites	5d, 1d, 2bc, 3de, 4c, 5d.	C, S, UC	2 years to germinate.
Libocedrus decurrens, incense cedar.	L	North and west slopes.	1cd, 2c, 3c, 4b	S, B	Use fresh seed in fall.
Pinus attenuata, knob-cone pine.	L	Exposed south and east slopes.	1bc, 3bc, 5b	S, B	Nursery stock or sow seed in fall.
Pinus coulteri, Coulter pine	L	North slopes	5b-d		
Pinus jeffreyi, Jeffrey pine	L	Well-drained soils	1d, 2c, 3d, 4b, 5d.		
Pinus ponderosa, ponderosa pine.	L	do	1d, 2c, 3c, 4b, 5d.		
Pinus radiata, Monterey pine.	L	Well-drained soils, coastal.	1a (1,500 feet and below).		
Pinus sabiniana, digger pine	L	Hot, dry sites	1bc, 3b, 5b		
Sequoia sempervirens, redwood.	L	Cool, moist sites	1a		
Broadleaf evergreens:					
Arbutus menziesii, Pacific madrone.	M, L	Abundant moisture, well-drained soils.	1ac, 3c, 5a	S, B	Sow seed in spots.
Heteromeles arbutifolia, Christmasberry.	S	Hot, dry slopes	1ab, 3b, 5ab	S, UC, C	Sow fresh seed.
Lithocarpus densiflora, tanbark oak.	L	Rich, moist, sandy, gravelly soils.	1acd, 3c, 5c	S, B	Plant acorns.
Quercus agrifolia, coast live oak.	L	Hot, dry sites	1ab, 5ab	S, B	Plant acorns as soon as gathered.
Quercus chrysolepis, canyon live oak.	L	Canyons, partly shaded sites.	All of 1, 2ac, 3bc, 4b, 5bcd.	S, B	
Quercus dumosa, California scrub oak.	S	Hot, dry slopes	1b, 3b, 5abc	S, C	

[1] Symbols indicate approximate heights of mature plants as follows:

Symbol	Size	Trees	Shrubs	Perennials and annuals
L	Large	Over 40 feet	6 to 15 feet	2½ feet and more.
M	Medium	25 to 40 feet	4 to 8 feet	1 to 2 feet.
S	Small	15 to 25 feet	4 feet and less	2 to 12 inches.

[2] Symbols indicate position on slope (fig. 5) as follows:

Symbol:	*Position on slope*
UC	Upper corner.
S	Side of fill slope.
B	Bottom of fill.
C	Center of slope.
UE	Upper edge of fill.
RS	Road shoulder.
EC	Edge of cut bank.

[3] Sowing of fresh seed in the fall is recommended for most native species throughout California. Thus, natural exposure to winter temperatures favors germination the following spring. Where rodents are abundant direct sowing of seed of many species may have to be preceded by rodent control or abandoned in favor of planting nursery stock because of the avidity of the rodents for the seed.

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[12] Plants for Region 6 are listed separately at end of table 2.

TABLE 2.—*Plant list for the California region*—Continued

Species	Size [1]	Native habitat	Planting district	Position on slope [2]	Remarks
Broadleaf deciduous:					
Acer macrophyllum, bigleaf maple.	L	Canyons, protected sites.	1abcd, 2c, 3c, 5abcd.	S, B	Sow fresh seed.
Acer negundo var. *californicum*, boxelder.	M	Living stream banks.	1abc, 3a	S, B	
Aesculus californica, California buckeye.	S	Hot, dry slopes	1ab, 3ab, 5ab	C, UC	Sow nuts in fall with leafmold.
Fraxinus dipetala, chaparral or foothill ash.	S	do	1bc, 3b, 5bc	S, C	
Fraxinus oregona, Oregon ash.	S	Living stream beds	1abcd, 2ac, 3abc, 5ac		Sow in early fall.
Fraxinus velutina, velvet ash.	M	Hot, dry slopes	5c, 6abcd		
Juglans californica, California walnut.	S	Canyons, well-drained slopes.	5ab	UC, S	Plant nuts as soon as gathered, or stratify.
Juglans hindsii, Hinds walnut.	L	do	Bay region		
Platanus racemosa, California sycamore.	L	Stream banks	3a, 5ab	S, B	Plant nursery stock.
Quercus garryana, Garry oak	M	Moist well-drained slopes.	1ac, 2a	S, B	Plant acorns as soon as gathered.
Quercus kelloggii, California black oak.	L	do	1acd, 2c, 3c, 4b, 5cd.		
Robinia pseudoacacia, black locust (not native).	L	Hot, dry sites	Below 1,500 feet.	S, B	Plant soaked seed or nursery stock.
Shrubs:					
Acer glabrum, dwarf maple	L	Moist, well-drained slopes.	1d, 2c, 3cd, 4bc, 5d.	S, C	Sow seed as soon as gathered.
Amelanchier alnifolia, common serviceberry.	L	Canyons, dry slopes.	5bc, 1bc, 2ad, 3d, 4ab.	S, UC	Showy shrub, white flowers.
Arctostaphylos stanfordiana	M	Fairly dry slopes	1b, 3bc	UC, S, C	Plant nursery stock.
Baccharis pilularis, kidneywort.	M	Hot, dry slopes	1ab, 3b, 5ab	C	Cuttings.
Baccharis viminea, mule fat, water motie.	M	Dry stream beds; moist slopes.	1ab, 3ab, 5ab	C	Do.
Berberis nevinii, barberry	M	Hot, dry slopes	Below 1,500 feet, 6abc.	C, UC	Sow seed in fall.
Calycanthus occidentalis, California sweetshrub.	M	Stream banks, moist sites.	1ab, 2a	C, UC	Red flowers, sow seed.
Carpenteria californica, carpenteria.	M	Fairly dry slopes	Below 1,500 feet.	C, UC	White flowering shrub.
Castanopsis sempervirens, Sierra chinquapin.	M	do	1cd, 2c, 3d, 4c, 5dc.	C, UC	Protect from rodents.
Ceanothus arboreus, tree ceanothus.	L	Hot, dry slopes	Below 1,500 feet.	S, B	Flowers blue
Ceanothus crassifolius, hoaryleaf ceanothus.	S	do	5ab	C	Seeds require hot-water treatment before sowing.
Ceanothus cuneatus, wedgeleaf ceanothus.	S	do	1b, 2b, 3b, 4a, 5ab.		
Ceanothus diversifolius, trailing bluebrush.	S	Partial shade, protected site.	1d, 2c, 3c		
Ceanothus integerrimus, deerbrush.	S	do	1cd, 2ac, 3c, 4b, 5cd.		
Ceanothus oliganthus, hairy ceanothus.	S	do	5b	C, UC	Flowers deep blue.
Ceanothus prostratus, squawcarpet.	S	do	1cd, 2c, 3c, 4b	C, EC	Transplant from forest.
Ceanothus thrysiflorus, blueblossom.	M	Hot, dry slopes	1ab	C	Hot-water treatment.
Cercis occidentalis, California redbud.	L	do	1b, 3b	C, UC	Showy shrub; flowers red-purple.
Chrysothamnus bloomeri, Bloomer rabbitbrush.	S	do	1d, 2bc, 3cd, 4bc, 5cd.	C, UC	Mix seed with sawdust and broadcast in fall.
Chrysothamnus nauseosus, rubber rabbitbrush.	S	do	2b, 3bc, 4a, 5c	C, UC	
Cornus nuttallii, Pacific dogwood.	L	Moist, well-drained slopes.	1acd, 2c, 3c, 4b, 5d.	C, UC	Stratify seed.
Corylus californica, California hazel.	L	do	1abcd, 3c	C, UC	Do.
Dendromecon rigida, bushpoppy.	L	Hot, dry slopes	1b, 3b, 5b	UC	Flowering shrubs.
Encelia californica, California encelia.	S	do	5a	C, UC	

TABLE 2.—*Plant list for the California region*—Continued

Species	Size [1]	Native habitat	Planting district	Position on slope [2]	Remarks
Shrubs—Continued.					
Eriodictyon californicum, California yerba-santa.	S	Hot, dry slopes	1b, 3b	C	Seed or root cuttings.
Eriodictyon trichocalyx, hairy yerba-santa.	S	do	5b		
Fremontia californica, flannelbush.	L	Hot, dry sites	1b, 3b, 5b	UC	Hot-water treatment.
Nicotiana glauca, tree tobacco.	L	Hot, dry sites, waste areas.	1a, 3ab, 5ab, 6abc.	S	
Philadelphus lewisii, Lewis mockorange.	M	Hot, dry sites	1bc, 2ac, 3c, 4b.	UC	Plant nursery stock.
Prunus emarginata, bitter cherry.	M	do	1cd, 2abc, 3c, 4b, 5cd.	UC, C	Sow fresh, cleaned seed in fall.
Prunus ilicifolia, hollyleaf cherry.	L	do	5ab	UC, C	
Prunus integrifolia, evergreen cherry.	L	do	Below 1,500 feet.	UC, C	
Rhamnus californica, California buckthorn.	L	do	1a, 5a	UC	
Rhamnus crocea var. *ilicifolia*, hollyleaf buckthorn.	L	do	1a, 3ab, 5ab	UC	
Rhus integrifolia, mahogany sumac.	L	do	5a	C, UC	Requires pretreatment, sulphuric acid.
Rhus laurina, laurel sumac	M	do	5a	C, UC	Soak seed in hot water.
Rhus ovata, sugarbush sumac.	L	do	5ab	C, UC	Requires pretreatment, sulphuric acid.
Salvia apiana, white sage	M	do	5ab	C, UE	Sow seed in spots, cover lightly.
Salvia leucophylla, whiteleaf sage.	S	do	5a		
Salvia mellifera, black sage	M	do	5ab, 3b, 1b		
Senecio douglasii, desert ragwort.	M	do	3ab, 5ab, 6abc	C, UE	Sow fresh seed.
Wyethia helenioides, mules-ears.	S	do	1a, 3ab	C	Sow seed after 2 months' storage.
Wyethia mollis, mules-ears	S	do	1d, 2c, 3d, 4bc	C	Sow fresh seed in fall.
Perennials and subshrubs:					
Atriplex semibaccata, Australian saltbush.	M	Alkaline sites	Below 2,000 feet.	RS, UE, EC.	Low spreading plant.
Delphinium hansenii, Hansen larkspur.	L	Dry sites	Below 3,500 feet.	UE, RS	Broadcast seed.
Diplacus aurantiacus, bush monkeyflower.	M	Hot, dry sites	1ab, 3ab	UE, C	Broadcast seed in January.
Eschscholtzia californica, California-poppy.	M	do	Below 3,500 feet.	UE, RS	
Helianthus gracilentus, sunflower.	M	do	5ab	C	
Lotus scoparius, deerweed trefoil.	M	do	Below 3,500 feet.	C, UE, EC.	Scarify seed.
Lupinus albifrons, lupine	L	Open hillsides	Below 5,000 feet.	UE, C	Seed spot, hot-water treatment.
Lupinus arboreus, tree lupine.	L	Canyons, open sandy sites.	1 coastal		
Lupinus longifolius, lupine	L	Canyons	5b		
Lupinus formosus, lupine	M	Dry, open areas	Below 2,000 feet.	C, UE	
Pentstemon breviflorus, stubflower pentstemon.	L	Hot, dry sites	1bc, 3ab, 5a	UE	Broadcast with sawdust.
Pentstemon cordifolius, heartleaf pentstemon.	L	do	5a	UE	
Pentstemon spectabilis, showy pentstemon.	L	do	5ab	UE	
Annuals and biennials: [4]					
Clarkia elegans, clarkia	M	do	Below 5,000 feet.	UE, RS	Flowers purple or rose.
Collinsia bicolor, Chinese-houses.	M	Partially shaded slopes.	Below 3,000 feet.	UE, RS	
Gilia tricolor, gilia	S	Hot, dry slopes	Below 2,000 feet.	RS, UE	
Godetia amoena, farewell-to-spring.	M	do	Below 3,500 feet.	UE, RS	Flowers red-pink.
Helianthus annuus, common sunflower.	L	do	Below 2,000 feet.	C	Broadcast seed.

[4] Sow seed in place and rake lightly.

TABLE 2.—*Plant list for the California region*—Continued

Species	Size[1]	Native habitat	Planting district	Position on slope[2]	Remarks
Annuals and biennials—Contd.					
Lupinus densiflorus, lupine	M	Hot, dry slopes	Below 3,500 feet.	UE, RS	Hot-water treatment.
Lupinus nanus, lupine	M	do	do	UE, RS	
Lupinus sparsiflorus, lupine	M	do	do	UE, RS	
Lupinus stiversii, lupine	M	do	3c	UE, RS	
Lupinus succulentus, lupine	M	do	Below 1,500 feet.	UE	
Orthocarpus purpurascens, escobita, owlclover.	S	do	Below 3,500 feet.	UE, RS	
Creepers (evergreen):					
Fragaria californica, wild strawberry.		Shade, protected sites.	1abc, 2abc, 3bcd, 4bc, 5abcd.	UE, EC, RS.	Cuttings (rooted).
Lippia repens, fogfruit		Dry slopes	3abc,5ab		
Mesembryanthemum aequilaterale, sea-fig.		Coastal sites	Below 1,500 feet.	UE, EC, RS.	Plant 6-in. cuttings cured 2 days in sun.
Mesembryanthemum croceum, iceplant.		Drought resistant	do	UE, EC, RS.	
Salvia sonomensis, creeping sage.		Dry slopes	1ab, 3ab, 5ab	UE, RS	Cuttings or runners.
Vitis californica, California grape.		Shade, protected sites.	1ab, 3ab	UE, EC	
Vitis girdiana, desert grape		do	5ab, 4ab	UE, EC	
Vinca major, bigleaf periwinkle.		Partially shaded, moist sites.	Below 5,000 feet.	UE, RS	Cuttings; require shade.
Grasses:					
Elymus condensatus, giant wildrye.	L	Dry, open sites	Below 3,000 feet.	EC, RS, C, UE.	Perennial. Seed and sod.
Elymus glaucus, smooth wildrye.	M	Partial shade	All elevations		
Melica imperfecta, California melic.	M	Dry, open sites	Below 5,000 feet.	EC, RS, C, UE.	Perennial.
Poa scabrella, pine bluegrass.	M	do	Below 6,000 feet.	EC, RS, C, UE.	Perennial. Seed and sod.
Stipa coronata, crested needlegrass.	L	do	5 ab		
Stipa pulchra, nodding needlegrass.	M	do	Below 3,000 feet.		
ADDITIONAL SPECIES FOR DISTRICT 6					
Trees:					
Cercidium floridum, border paloverde.	S	Hot, dry slopes	6abc	UC, S, B	Treat seeds with hot water.
Chilopsis linearis, desert-willow.	S	Hot, dry, open flats and slopes.	6abc	UC, S, B	
Juniperus californica, California juniper.	S	Hot, dry slopes	6abcd	UC, S, B	Stratify.
Parkinsonia aculeata, Jerusalem-thorn.	S	Dry, open flats or valleys.	6abc	UC, S, B	Treat seeds with hot water.
Pinus monophylla, singleleaf piñon.	S	Hot, dry slopes	6abcd	S, B	Stratify.
Pinus quadrifolia, Parry pine.	S	Hot, dry, open flats and slopes.	6abcd		
Prosopis glandulosa, honey mesquite.	S	Hot, dry slopes	6abc	UC, S, B	Treat seeds with hot water.
Shrubs:					
Aplopappus parishii =*Ericameria p.*), goldenbush.	M	Chaparral slopes	6abc	UE, UC	Sow seed in fall.
Atriplex canescens, fourwing saltbush.	M	Dry, open flats and valleys, and alkaline plains.	6abc	UE, C	
Atriplex hymenelytra, desert-holly.	S	do	6abc		Sow seeds in fall.
Atriplex lentiformis, quailbrush.	L	do	6abc		
Baccharis emoryi, Emory baccharis.	M	River washes	6ab	UE, C, B, S.	Sow seeds in fall or transplant rootstocks.
Baccharis glutinosa, seepwillow; water-wally.	M	River washes of desert.	6abc	UE, C, B, S.	Plant cuttings in fall and winter.
Baccharis viminea, mule-fat, water-motie.	M	River washes and slopes.	6abc		

TABLE 2.—*Plant list for the California region*—Continued

Species	Size [1]	Native habitat	Planting district	Position on slope [2]	Remarks
Shrubs—Continued.					
Cercocarpus ledifolius, curl-leaf mountain-mahogany.	L	Canyons, full sun	6abcd	UC, S, B	Stratify.
Emplectocladus andersonii (=*Prunus a.*), Anderson peachbrush; desert peach.	M	Dry, open flats and slopes.	6abc	UC, S, C, B.	Sow seed in fall.
Eriogonum fasciculatum, flattop buckwheatbrush.	S	Dry slopes, flats, valleys and canyons.	6abc	UE, S, B	Sow seed in fall.
Lepidospartum squamatum, broombrush; "green broom".	S	Washes and gravelly plains.	6abc	UE, S, B	Sow seed in fall or transplant rootstocks.
Sambucus caerulea, blueberry elder.	L	Dry slopes, flats, valleys, and canyons.	6abcd	UC, S, B	Plant cuttings when dormant.
Senecio douglasii, desert ragwort.	M	do	6abc	S, C, B	Sow seed in fall.
Herbs:					
Coreopsis bigelovii	S	Desert flats	6abcd	RS, UE	Perennial. Sow seed in fall.
Gilia aggregata, tinpiute; scarlet gilia.	M	Loose soil on sunny slopes.	6abc	UE, RS	
Malacothrix coulteri, "snake's head".	S	Sandy valleys, deserts.	6abcd	RS, UE	
Salvia carduacea. thistle sage.	M	Valley plains, mesas, and canyon flats.	6abc	UE, RS	Annual. Sow seed in fall.
Grasses:					
Aristida californica, Mohave three-awn.	M	Deserts	6abc	EC, RS, C.	Perennial. Sow seed in fall.
Stipa speciosa, desert needlegrass.	M	Deserts and arid hills.	6abc	EC, RS, C.	Perennial. Sow seed in fall or plant sods.

F.—NOTES ON HANDLING AND SOWING SEED

The simple cultural directions in the "Remarks" column of the plant list are necessarily extremely brief. They are condensed chiefly from a manuscript report now in preparation by the experiment station presenting the results of several years of investigation of seed treatment, germination, and other cultural requirements of native California plant species. Pending publication of that report, the following amplifications of the cultural "Remarks" are offered for the benefit of those who may require them.

SOW FRESH SEED IN FALL

With few exceptions best results are obtained by this imitation of nature's own method of direct sowing. Because of the magnitude of the planting job, the impossibility of securing enough nursery-grown plants (other than the principal conifers) to fill the needs, and the high cost of producing such stock, effort has been directed toward developing methods of direct sowing. The seed of desirable early-fruiting species can be collected as it ripens throughout the summer in the vicinity of a road project and kept in storage until fall.

For shrubs and trees which are to be spaced several feet apart seeds are best sown in "seed spots" in which the soil, in patches 12 to 14 inches in diameter, is dug up and pulverized as in a garden. In each spot 3 to 10 seeds are sown, depending on the germinability of the seed. Most seed should be covered with soil to a depth of 2 or 3 times its diameter but rarely more than one-half inch. In sandy soils sowing can be deeper than in clay soils. Very small seed should be merely scattered on the soil surface and lightly raked in. Acorns should be pressed sidewise into the loose soil and covered with 2 or 3 inches of leaf mold. Under arid conditions a light covering of leaf mold will benefit most species by protecting the seed spot against drying. In clay soils such a mulch will prevent the soil from "baking" and imprisoning the young seedling.

STORAGE OF SEED

Most seeds can be kept for a few months in ordinary paper or cloth sacks in a cool, dry room without serious loss in germinability. If seed is to be held over a year or more it should be thoroughly air-dried and then cold-stored in airtight tins or glass jars in a temperature range of 35° to 40° F. Fleshy seeds such as acorns and walnuts should never be permitted to become thoroughly dried out. If these are to be held more than a few weeks they should be stratified, i. e., placed in boxes in alternate layers with damp peat-moss or light soil in cold storage at 33° to 35°. The temperature range should be kept just above the freezing point and yet well below 40°, at which point the sprouting of acorns may begin. Stratified seed should be inspected frequently to see that it is kept properly moist and free from decay. If fungus growth is observed the surface of the soil should be sprinkled with cupric oxalate powder at the rate of 4 grams of powder per square foot of soil surface.

HOT WATER AND OTHER TREATMENTS

Some species which have hard seed coats yield only 3 to 10 percent germination under ordinary conditions. Soaking such seed in hot water increases the germination rate to more than 70 percent. The method is simply to pour boiling water over the seed and let it soak over night. The volume of water should be three or four times that of the seed. Soaked seed should be sown or stratified immediately without being permitted to dry out. Scarification, required for lotus and some grass seeds, is accomplished by rubbing the seed with sandpaper. Large lots can be treated by placing the seed in a box or barrel lined with sandpaper and rotating the container until the seed is sufficiently abraded. Sulphuric-acid treatment involves soaking the dry seed in concentrated acid, but the process is attended by so many variable conditions that it cannot be adequately described in the present publication.

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U. S. GOVERNMENT PRINTING OFFICE: 1936